Appendix C
Flood Risk Management and Geomorphic Conditions Supplemental Environmental Setting, Flood Risk Management and Geomorphic Reports

Part C.1

Additional environmental setting information in support of Section 3.1, *Flood Risk Management and Geomorphic Conditions*

Parts C.2, C.3, C.4, and C.5

William Lettis and Associate's Surficial Geologic Maps and Geomorphic Assessment of the Sutter Study Area, Urban Levee Geotechnical Evaluation, Sutter and Butte Counties, California

From URS Supplemental Geotechnical Data Report (2010), Appendix O, Volumes 2 through 5

Parts C.6 and C.7

Feather River West Levee Project Design Water Surface Profiles, PBI, March 2012

Feather River West Levee Project Design Water Surface Profiles Addendum #1, PBI, July 2012

Part C.8

'With-Project' Hydraulics Analysis for the Feather River West Levee Project, PBI, October 2012

Part C.1

Supplemental Environmental Setting

Part C.1
Supplemental Environmental Setting

This appendix provides additional environmental setting information in support of Section 3.1, *Flood Risk Management and Geomorphic Conditions.*

C.1.1 Flooding

C.1.1.1 Flood Basins of the Sacramento Valley

The importance of natural flood basins to the Sacramento Valley river system was recognized by Gilbert as early as 1917 (Gilbert 1917; Water Engineering & Technology 1990:32–33). Flood basins in the Sacramento Valley were originally delineated by Gilbert. More recently, Ayres Associates (2008:16–17) divided the entire Sacramento River basin into potential flooded areas, based on the land that would be flooded if a levee failure occurs. The Sacramento River basin was divided into 26 sub-basins (Ayres Associates 2008:16–17, Figures 5 and 6).

Gilbert (1917) and discussed in Water Engineering & Technology (1990:32–33) described these flood basins as being inundated annually by floodwaters. The Sacramento River was separated from the flood basins by natural levees; however, at high water, these levees were easily overtopped. The lower 25 miles of the Feather River (approximately 18 miles of which are in the proposed project area) is also bounded by flood basins (Water Engineering & Technology 1990:32–33).

Hall (1880 as cited in Water Engineering & Technology 1990:32–34) describes the inundation of the flood basins during the flood of 1879:

> During the high water of March 1879, the low lands of the Sacramento Valley, to the extent of about 847 square miles, were covered with water; this area includes all flooded for a short period of time, as well as that upon which the water rested for several months. Above the mouth of the Feather River, in what may be called the upper flood region, the area covered was about 483 square miles; and below that point, in what is called the lower flood region, the flooded area was about 364 square miles in extent.

Gilbert (1917:15) emphasized the hydrologic significance of the natural flood basins:

> The lateral basins affected the channel characters in important ways. They conveyed a large part of the flood discharge and thus left for adjacent portions of the channel only a small part. They acted as reservoirs for the storage of floodwaters and fed them gradually to the lower course of the Sacramento, so that the channels in the delta region were only moderately taxed by the floods. The channels in consequence were adjusted for conveyance of only a fraction of the flood discharge; they were of moderate section and their meanders were of small radius. Between the town of Colusa and the mouth of the Feather River the Sacramento River grows gradually smaller downstream until its estimated capacity is only 10 per cent of the flood discharge.

Because the flood basins have been maintained as topographic lows even though there has been extensive overbank deposition, it is evident that the flood basins have been subsiding at a rate equal to or exceeding that of overbank deposition (Gilbert 1917; Water Engineering & Technology 1990:34; Water Engineering & Technology 1989 as cited in Water Engineering & Technology 1990:34; Harvey 1988 as cited in Water Engineering & Technology 1990:34). Such widespread subsidence perhaps is driven by ongoing structural deformation of the Sacramento Valley. Offset on the Willows fault could have generated an east-dipping topographic gradient on the eastern, upthrust block. Rotation of the downthrust block could have generated a similar gradient (Water Engineering & Technology 1990:34–35). See Section 3.3, *Geology, Soils, Seismicity, and Mineral Resources*, for further information about land subsidence in the proposed project area.

In brief, the Sacramento Valley flood basins play a key role in the fluvial geomorphology and hydrology of the Feather River. Most importantly, suspended sediment that historically has been deposited in the flood basins has produced a thick, cohesive stratigraphic assemblage, which adds to the bank stability of the lower Feather River. The significance of these flood basin deposits increases downstream as the topographic lows become more prevalent (Water Engineering & Technology 1990:35).

C.1.2 Geomorphic Conditions

C.1.2.1 Channel Network Classification

Valley morphology varies going downstream in most watersheds, such as the Feather River watershed. Because of this variation, watersheds are divided into valley segments and channel reaches. Valley segments are distinctive sections of the valley network that possess geomorphic properties and hydrologic transport characteristics that distinguish them from adjacent reaches (Bisson and Montgomery 1996:26).

Valley segments can be classified into three classes based on their position within the watershed and the relative ratios of transport capacity to sediment supply (Montgomery and Buffington 1998:23–24). Headwater source areas typically are transport-limited (often because of limited channel runoff) but do offer sediment storage that is intermittently initiated under large flow events, debris flows, or other gravitational events (e.g., landslides). Transport segments are composed of morphologically resilient, supply-limited reaches (e.g., bedrock, cascade, step-pool) that rapidly convey increased sediment inputs. Response segments consist of lower-gradient, more transport-limited depositional reaches (e.g., plane-bed, pool-riffle, step-pool sequences) where channel adjustments occur in response to changes in sediment supply delivered from upstream.

Based on field observations, literature review, and the stream classification methodologies described above, the Feather River in the proposed project area is an alluvial valley segment dominated by plane-bed and pool-riffle reaches. Plane-bed and pool-rifle reaches are transport-limited; therefore, the Feather River behaves as a response segment, theoretically adjusting its bed morphology to water and/or sediment. In general, it can be described as a sediment-laden, low-sinuosity stream.

C.1.2.2 Reach-Specific Geomorphic Conditions

From the Feather River's confluence with the Yuba River to river mile (RM) 7, levees confine the river within the Sutter Bypass. During flooding, overflow from the Sacramento River can enter the river through the Bypass and a backwater can form. The bed is made up of moving bars of sand, which can become mobile even during summer irrigation season (Foothill Associates 2010).

From RM 7 to RM 12.5, the Feather River is characterized by the presence of alternate gravel bars on the channel margins and large sand waves within the channel. The frequency of these sand waves increases upstream from Nicolaus. From RM 12.5 to RM 17, near the confluence with the Bear River, the Feather River is relatively wide and straight, and the upper bank sediments are composed of highly erodible, non-cohesive hydraulic mining-derived sands (Water Engineering & Technology 1990:8). For the most part, the bank on one side of the river consists of floodplain silt and sand overlying slickens, while the opposite bank is made up of active point bar deposits of sand with some silt, which indicates that some bank erosion and channel migration is occurring (Foothill Associates 2010). Fluvial entrainment and dry gravel of upper bank sediments are common; however, the resistance of the toe bank, composed of fine-grained hydraulic mining debris (slickens), contributes to planform stability (Water Engineering & Technology 1990:8).

From RM 17 to RM 28, the resistant Pleistocene Modesto Formation commonly forms the channel banks of the Feather River so that channel planform is relatively stable. Several distinct bendways are present within this reach (Water Engineering & Technology 1990:8). These large meanders occur near the bottom of the reach. The banks are made up mostly of floodplain deposits and the beds mostly of sand. The Shanghai Bend, a bench-like outcrop that forms a rapid, with a near-vertical drop of several feet in places, occurs in this reach (Foothill Associates 2010).

Near the confluence with the Yuba River, the Feather River is influenced by backwater effects from the Yuba River, which cause the river to become relatively straight with minimal bank instability and fewer meanders. The floodplain here, confined by older natural levee terrace deposits and built levees, is typically less than 1 mile across. The bed is sand and the banks are made up of floodplain deposits. There are few point bars or other depositional features and only a single channel (Foothill Associates 2010).From RM 29 to RM 61 (near Oroville), the levee embankment system is set back and the river occupies a wide meander belt similar to the Sacramento River upstream of Colusa. In general, the Feather River is a sand- to fine gravel–dominated, high-sinuosity channel upstream of Marysville to about RM 56. Upstream of RM 56, sinuosity decreases, split flow around mid-channel gravel bars is common, and sediment is dominated by coarse gravel to cobble-sized sediment. The river is bordered by gold mining dredge spoils in this upper reach (Water Engineering & Technology 1991:139–140).

More specifically, from RM 29 to RM 45, the Feather River is a sinuous meandering channel whose bed material is dominated by sand to fine gravel–sized sediment. The sediment coarsens gradually upstream through the reach. The river is highly dynamic and contains large point bars and chute channels. Bank erosion is extensive; however, wide levee setback precludes direct levee threat. Where the channel flows close to the levees, the resistant Pleistocene Modesto Formation commonly composes the channel banks (Water Engineering & Technology 1991:139–140). This section of river is unlike the other reaches because of its high sinuosity, active bank erosion, and point bar formation. These point bars are made up primarily of sand and minor gravel and are not armored. Meander cutoffs have occurred here and will likely continue to occur. The instability of this reach is likely related to the relatively fine composition (sand to fine gravel) of the bed and banks (Foothill Associates 2010).

From RM 45 to 54, high-flow sinuosity is low, split flow is common, and bed and bar sediment is dominated by gravel to cobble-sized material. This reach has a very high sediment load because of the presence of dredge spoils upstream. From RM 54 to RM 61, the Feather River flows through gold mining dredge spoils. The channel banks generally are composed of the spoils, which are dominated by sand to cobble-sized sediment. The river has been controlled within linear spoils piles so that the spoils border the river directly for several miles. As a result, sinuosity is low in this uppermost reach (Water Engineering & Technology 1991:139–140).

C.1.2.2.1 Surficial Geology

Previous geologic mapping in the southern proposed project area along the Feather River and surrounding areas generalize the surficial deposits as: Quaternary Alluvium (map unit Qa) and Quaternary stream channel deposits (map unit Qsc) within and proximal to the modern Feather River channel, (Helley and Harwood 1985). These map units are considered Holocene age (less than 11,000 years old). Late Quaternary Modesto Formation (map units Qmu, Qml) is mapped along the western margin of the floodplain.

Previous geologic mapping along the northern Feather River and surrounding areas generalizes the surficial deposits as: Quaternary alluvium (map unit Qa) and Quaternary stream channel deposits (map unit Qsc), which are mapped within and proximal to the modern Feather River channel (Bussaca et al. 1989 as cited in Appendix O of Volume 4 of URS 2010:3 [included in this report as Appendix C, part C.4]; Creely 1965 as cited in Appendix O of Volume 4 of URS 2010:3; Helley and Harwood 1985). These map units are considered Holocene in age (less than 11,000 years old). Late Pleistocene Modesto Formation (map units Qmu, Qml) is present as an escarpment along the western margin of the floodplain.

These map units were delineated by Helley and Harwood (1985) at a regional scale (1:62,500). A more current analysis of the Feather River area by William Lettis & Associates uses this existing geologic framework as a basis for more detailed mapping of late Holocene alluvium and geomorphic features (see Plate 1 of Appendix O of Volumes 4 and 5 of URS 2010 [included in this report as Appendix C, parts C.4 and C.5, and Plate 3.3-1 of this document).

The surficial geologic map units in and adjacent to the Feather River are described in Appendix O, "Geomorphology Report," in Volumes 4 and 5 of the URS (2010) report (included in this report as Appendix B). Additionally, for a description of surficial geologic units, refer to Section 3.3, *Geology, Soils, Seismicity, and Mineral Resources*.

Lower Feather River

Published geologic maps of the lower Feather River identify a complex series of westward aggrading alluvial fans and terraces derived from the Sierra Nevada, identified as the Riverbank and Modesto Formations. The Riverbank Formation and Modesto Formation are semi-consolidated to unconsolidated deposits characterized by intra-formational paleochannels and lateral and vertical stratigraphic complexity related to past fluvial processes and buried paleo-topography. The Riverbank Formation unconformably overlies the Laguna Formation, which is a deeply dissected alluvial surface (Busacca et al. 1989 as cited in Appendix O of Volume 4 of URS 2010:5) (Appendix O of Volume 4 of URS 2010:5 [included in this report as Appendix B]).

Subsurface deposits about 150 feet beneath the ground surface rest on a resistant volcanic tuff capped by interbedded alluvial gravel, sand, and silt, interpreted as Pliocene-Pleistocene age Laguna Formation that represents a period of relatively stable landscape conditions (Helley and Harwood 1985). The Laguna Formation is overlain by the Pleistocene Riverbank Formation, (very dense gravel deposits), which are, in turn, overlain by a medium dense sand and gravelly sand assemblage of the latest Pleistocene Modesto Formation (Busacca et al. 1989 as cited in Appendix O of Volume 4 of URS 2010:5 [included in this report as Appendix B]). The upper member of the Modesto

Formation is exposed at the ground surface adjacent to the western bank of the Feather River south of Marysville and Yuba City. The Modesto Formation is mantled by unconsolidated deposits of Holocene age that compose most of the surficial geologic deposits along the western side of the Feather River (Plate 1 of Appendix O of Volume 4 of URS 2010 [included in this report as Appendix B] and Plate 3.3-1 of this document) (Appendix O of Volume 4 of URS 2010:5).

Upper Feather River

Published geologic maps of the upper Feather River show a complex series of westward aggrading alluvial fans and terraces derived from erosion of the Sierra Nevada, identified as the Riverbank and Modesto Formations (Bussaca et al. 1989 as cited in Appendix O of Volume 5 of URS 2010:5 [included in this report as Appendix B]; Helley and Harwood 1985; Creely 1965 as cited in Appendix O of Volume 5 of URS 2010:5 [Appendix B]). The Riverbank Formation and Modesto Formation in general are semi-consolidated to unconsolidated deposits characterized by intra-formational paleochannels and lateral and vertical stratigraphic complexity related to past fluvial processes and buried paleo-topography. The oldest map unit, the Riverbank Formation unconformably overlies the Pliocene-Pleistocene age Laguna Formation, which consists of interbedded alluvial gravel, sand and silt (Busacca et al. 1989 as cited in Appendix O of Volume 5 of URS 2010:6 [Appendix B]; Helley and Harwood 1985). The overlying Pleistocene Riverbank Formation consists of very dense gravel deposits that are, in turn, overlain by a medium dense sand and gravelly sand package of the latest Pleistocene Modesto Formation (Busacca et al. 1989 as cited in Appendix O of Volume 5 of URS 2010:6 [included in this report as Appendix B]). The upper member of the Modesto Formation is exposed at the ground surface adjacent to the western bank of the Feather River. The Modesto Formation is locally mantled by unconsolidated, sand-rich Holocene deposits (Plate 1 of Appendix O of Volume 5 of URS 2010 [included in this report as Appendix B] and Plate 3.3-1 of this document). East of the Feather River, the older stratigraphic units are uplifted and dissected and younger deposits are inset into them with older deposits buried beneath younger deposits. West of the Feather River, the stratigraphic units are found in typical succession. This is the result of overall westward tilting and uplift of the Sierra Nevada, incision along the tributary drainages (i.e., Honcut creek), and progradational fan deposition west of the river (Appendix O of Volume 5 of URS 2010:5–6 [Appendix B]).

Surficial geologic mapping (Plate 1 of Appendix O of Volume 5 of URS 2010 [included in this report as Appendix B], and Plate 3.3-1 of this document) shows differences in deposit type and distribution from north to south along the northern Feather River proposed project area that primarily are associated with proximity to the Sierra Nevada mountain front near Thermalito Afterbay. These differences illustrate the diversity of past geomorphic processes along the river and, as a consequence, the type of geologic deposits at and near the ground surface. The surficial geologic map created by William Lettis & Associates allows the delineation of reaches along the river within which geomorphic processes and their associated deposits appear to be relatively consistent (Appendix O of Volume 5 of URS 2010:5–6 [included in this report as Appendix B]).

C.1.2.3 Channel Incision

Thalweg (channel centerline) profiles for the lower Feather River are shown in Figure 5.13 of Water Engineering & Technology (1990:81). The data sets incorporated in this figure represent 1911, 1924, and 1965 surveys. The profiles illustrate a degradational trend from 1911 to 1965, which is expected as channel incision into hydraulic mining debris has been documented (Meade 1982 as cited in Water Engineering & Technology 1990:80). The profiles show approximately 10 feet of degradation between 1924 and 1965 (Water Engineering & Technology 1990:80–81).

The Sutter Bypass has its confluence with the Feather River at RM 7.5 (the bottom of the proposed project area). From this point downstream, approximately 5 feet of incision occurred between 1911 and 1924 versus about 2 feet upstream during the same period. Increased flows introduced by the Sutter Bypass may have served to increase the rate of incision into hydraulic mining debris along this lower reach (Water Engineering & Technology 1990:80–81).

Thalweg profiles for the upper Feather River are shown in Figure 6.8 of Water Engineering & Technology 1991:155. The data sets incorporated in this figure represent 1909 and 1964 surveys. The profiles illustrate a significant degradational trend during this time period, which is expected as channel incision into hydraulic mining debris has been documented (Meade 1982 as cited in Water Engineering & Technology 1990:80). The profiles show the greatest amount degradation (approximately 10 feet) at the lower end of the upper proposed project area. The reason the Feather River in the upper proposed project area has not degraded in the upper reaches is attributable to the sediment supply that is maintained by lateral erosion of the dredge spoils that border the channels. In addition, flow regulation has affected the rate of incision. As only infrequent flows can entrain coarser material, channel incision into the debris is relatively slow. Farther downstream, the lower reaches have degraded because of the presence of finer materials (Water Engineering & Technology 1991:150–156).

C.1.2.4 Sinuosity, Channel Migration, and Bank Failure

In the lower proposed project area, historical observations and present-day channel sinuosity upstream of the Yuba River confluence suggest that the Feather River was more sinuous prior to hydraulic mining than it is today. In general, sinuosity increases with distance upstream. This increase in sinuosity reflects the increase in the upstream presence of the resistant Pleistocene Modesto Formation, which has helped to maintain the channel planform. Present-day sinuosity on the Feather River is not substantially different from that of the 1920s. The channel has incised into cohesive hydraulic mining debris (slickens), which has helped to maintain the channel planform. Additionally, flow regulation by upstream dams in the watershed has contributed to the maintenance of the channel planform. Whether sinuosity of the Feather River will increase back to pre-mining levels is unclear; such an increase is dependent on the depositional thickness of the cohesive toe sediment (slickens). If the river degrades through the slickens and less cohesive sediments compose the lower bank, channel migration rates and sinuosity may increase rapidly. Further evidence for the current planform stability is provided by the presence of the extensive riparian vegetation that is located near the water’s edge (Water Engineering & Technology 1990:77–80).

In the upper proposed project area, modes of bank failure and thus channel migration are highly dependent on bank lithology and stratigraphy. Along the Feather River in the upper proposed project area, coarse-grained point bar deposits are commonly preserved in the channel banks; fluvial entrainment of these sediments is followed by cantilever failure of the more cohesive upper bank vertical accretion sediments. Abandoned channel fill deposits form resistant hard points on the channel bank; where these deposits are located in the lower bank, bank retreat over the top of the resistant abandoned channel fill deposits can occur (Water Engineering & Technology 1991:149).

The greatest concentration of eroding banks is between RM 29 to RM 45, where the Feather River is a sinuous meandering channel whose bed material is dominated by sand to fine gravel–sized sediment. The river in this reach is highly dynamic and contains large point bars and chute channels. Bank erosion is extensive; however, as mentioned above, wide levee setback precludes direct levee threat in many locations.

Migration rates in the upper proposed project area are highly variable, reflecting the heterogeneity of materials present, and the range and stages of channel bend development (Harvey 1988 as cited in Water Engineering & Technology 1991:150). Although lateral migration rates are commonly high in the upper proposed project area, levee setback is sufficient so that very little direct levee threat exists (Water Engineering & Technology 1991:139–140).

C.1.2.4.1 Bank Retreat Rates: Feather River (RM 0–28)

Water Engineering & Technology (1990:172–173) conducted an analysis of migration rates for the lower Feather River bank lines. Bankline migration rates (for the west bank) averaged approximately 6 feet of migration per year, with a minimum value of 0 feet per year and a maximum value of 26.5 feet per year. At the time the study was conducted (1990), based on projected migration rates, the lower Feather River levees on the west bank were not anticipated to be threatened over a 15-year interval (Water Engineering & Technology 1990:172). Current-day field observations support this conclusion that bank retreat is slow on this reach, as erosion appears intermittent, the bank toe is cohesive, and mature vegetation is growing along the water's edge.

C.1.2.4.2 Bank Retreat Rates: Feather River (RM 28–61)

Water Engineering & Technology (1991:150–153) conducted an analysis of migration rates for the upper Feather River bank lines. Bankline migration rates (for the west bank) are commonly high (especially between RM 29 to RM 45), with an average of approximately 5 feet of migration per year, with a minimum value of 1.4 feet per year and a maximum value of 20.3 feet per year.

C.1.3 References Cited

Ayres Associates. 2008. 2008—Field Reconnaissance Report of Bank Erosion Sites and Site Priority Ranking, Sacramento River Flood Control Levees, Tributaries, and Distributaries. Sacramento River Bank Protection Project, Contract No. WA91238-07-D-0038 Modification to Task Order 2. Prepared for U.S. Army Corps of Engineers, Sacramento District. Sacramento, CA and Fort Collins, CO. December 18.

Bisson, P. A. and D. R. Montgomery. 1996. *Valley Segments, Stream Reaches, and Channel Units*. In: Hauer, F.R. and Lamberti, G.A. (eds.). Methods in Stream Ecology. San Diego, CA: Academic Press. 23–52.

Busacca, A. J, M. J. Singer, and K. L. Verosub. 1989. Late Cenozoic Stratigraphy of the Feather and Yuba Rivers Area, California, with a Section on Soil Development in Mixed Alluvium at Honcut Creek. U.S. Geological Survey Bulletin 1590-G. As cited in: URS. 2010. Supplemental Geotechnical Data Report (SGDR), Sutter Study Area. Urban Levee Geotechnical Evaluations Program, Contract 4600007418. Sacramento, CA. Prepared for California Department of Water Resources. April 2010.

Creely, R. S. 1965. Geology of the Oroville Quadrangle, California, California Division of Mines and Geology Bulletin 184. As cited in: URS. 2010. Supplemental Geotechnical Data Report (SGDR), Sutter Study Area. Urban Levee Geotechnical Evaluations Program, Contract 4600007418. Sacramento, CA. Prepared for California Department of Water Resources. April 2010.

Foothill Associates. 2010. Lower Feather River HUC/Honcut Creek Watershed Existing Conditions Assessment. Rocklin, CA. Prepared for Sutter County Resource Conservation District. Yuba City, CA. February.

Gilbert, G. K. 1917. Hydraulic Mining Debris in the Sierra Nevada. U.S. Geological Survey Professional Paper 105.

Hall, W. H. 1880. Report of the State Engineer to Legislature of California, 23rd Session, Part 3, Sacramento, CA. As cited in: Water Engineering & Technology. 1990. Geomorphic Analysis and Bank Protection Alternatives Report for Sacramento River (RM 78–194) and Feather River (RM 0–28). Contract no. DACW05-88-D0044. Deliver Order #5. Prepared for U.S. Army Corps of Engineers, Sacramento District. Fort Collins, CO. May.

Harvey, M. D. 1988. Meanderbelt Dynamics of the Sacramento River, California. Proceedings of the 2nd California Riparian Systems Conference. Davis, CA. As cited in: Water Engineering & Technology. 1990. Geomorphic Analysis and Bank Protection Alternatives Report for Sacramento River (RM 78–194) and Feather River (RM 0–28). Contract no. DACW05-88-D0044. Deliver Order #5. Prepared for U.S. Army Corps of Engineers, Sacramento District. Fort Collins, CO. May. And, as cited in: Water Engineering & Technology. 1991. Geomorphic Analysis and Bank Protection Alternatives Report for Sacramento River (RM 0–78), Feather River (RM 29–61), Yuba River (RM 0–11), Bear River (RM 0–17), American River (RM 0–23), and portions of Three Mile, Steamboat, Sutter, Miner, Georgiana, Elk and Cache Sloughs. Contract no. DACW05-88-D0044. Delivery Order #14, (Modifications #01, #02), Delivery Order #15. Prepared for U.S. Army Corps of Engineers , Sacramento District. Fort Collins, CO. June.

Helley, E. J. and D. S. Harwood. 1985. Geologic Map of the Late Cenozoic Deposits of the Sacramento Valley and Northern Sierran Foothills. California. U.S. Geological Survey miscellaneous field studies map MF-1790, 24 p., scale 1:62,500, 5 sheets. Sacramento, CA.

Meade, R. H. 1982. *Sources, Sinks, and Storage of River Sediment in the Atlantic Drainage of the United States*. Journal of Geology 90(3):235. As cited in: Water Engineering & Technology. 1990. Geomorphic Analysis and Bank Protection Alternatives Report for Sacramento River (RM 78–194) and Feather River (RM 0–28). Contract no. DACW05-88-D0044. Deliver Order #5. Prepared for U.S. Army Corps of Engineers, Sacramento District. Fort Collins, CO. May.

Montgomery, D. R. and J. M. Buffington. 1998. *Channel Processes, Classification, and Response*. In: Naiman, R. and Bilby, R. (eds.). River Ecology and Management. New York: Springer-Verlag.

URS. 2010. Supplemental Geotechnical Data Report (SGDR), Sutter Study Area. Urban Levee Geotechnical Evaluations Program, Contract 4600007418. Sacramento, CA. Prepared for California Department of Water Resources. April 2010.

Water Engineering & Technology. 1989. Geomorphic Analysis of Reach from Colusa to Red Bluff Diversion Dam, River Mile 143 to River Mile 243: Final Phase II Report. Rep. No. DACWO5-87-C-0094. Prepared for U.S. Army Corps of Engineers. Fort Collins, CO. As cited in: Water Engineering & Technology. 1990a. Geomorphic Analysis and Bank Protection Alternatives Report for

Sacramento River (RM 78–194) and Feather River (RM 0–28). Contract no. DACW05-88-D0044. Deliver Order #5. Prepared for U.S. Army Corps of Engineers, Sacramento District. Fort Collins, CO. May.

Water Engineering & Technology. 1990. Geomorphic Analysis and Bank Protection Alternatives Report for Sacramento River (RM 78–194) and Feather River (RM 0–28). Contract no. DACW05-88-D0044. Deliver Order #5. Prepared for U.S. Army Corps of Engineers , Sacramento District. Fort Collins, CO. May.

Water Engineering & Technology. 1991. Geomorphic Analysis and Bank Protection Alternatives Report for Sacramento River (RM 0–78), Feather River (RM 29–61), Yuba River (RM 0–11), Bear River (RM 0–17), American River (RM 0–23), and portions of Three Mile, Steamboat, Sutter, Miner, Georgiana, Elk and Cache Sloughs. Contract no. DACW05-88-D0044. Delivery Order #14, (Modifications #01, #02), Delivery Order #15. Prepared for U.S. Army Corps of Engineers , Sacramento District. Fort Collins, CO. June.

Part C.2

URS Supplemental Geotechnical Data Report (2010), Appendix O, Volume 2

APPENDIX O

Geomorphology Report

WLA

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September 8, 2009

Mr. Juan Vargas
URS Corporation
2870 Gateway Oaks Drive, Suite 150
Sacramento, CA 95833

RE: Surficial geologic mapping and geomorphic assessment, California Department of Water Resources Urban Levees, Wadsworth Canal, Sutter County, California

Dear Mr. Vargas:

This memorandum presents the surficial geologic mapping and preliminary geomorphic assessment of the Wadsworth Canal area, for the California Department of Water Resources (DWR) Urban Project Levees geotechnical characterization. The goal of this mapping and geomorphic assessment is to provide information on the type and distribution of surface and shallow subsurface deposits that likely underlie the project levees along the canal, with respect to potential levee underseepage. This letter presents the technical approach, surficial geologic map, conceptual geomorphic model, and initial results based on map analysis and preliminary review of Phase 1 geotechnical data.

We appreciated the opportunity to provide these geomorphic and geologic data and preliminary interpretations of the shallow stratigraphic conditions in the Wadsworth Canal study area. Please do not hesitate to call either of the undersigned if there are any questions or comments.

Respectfully,

WILLIAM LETTIS & ASSOCIATES, INC.

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1.0 Approach

The approach to developing a surficial geologic map of the Wadsworth Canal area (Figure 1, Plate 1) consisted of analysis of the following data: Aerial photography (black and white stereo-pairs taken in 1937, ~1:20,000-scale); early topographic maps (USGS, 1911); published surficial geologic maps (Helley and Harwood, 1985); early and modern soil survey maps (Strahorn et al., 1911; Lytle, et al., 1988); field reconnaissance visit on June, 22, 2007, and other maps and documents (i.e., Chambers, 2002). Synthesis of these data allow for the development of a detailed surficial geologic map that provides an initial understanding of primary geomorphic processes that have acted in the study area during recent geologic and historical time. Through this mapping, primary geomorphic features and associated surficial geologic deposits are identified, such as abandoned paleochannels, marsh and basin deposits, and other features commonly associated with flood basins adjacent to large, active river systems.

The surficial geologic map was developed at the nominal scale of the aerial photography (1:20,000). This scale establishes the resolution of the map (Plate 1). The map unit contacts shown on the surficial geologic map should be considered approximate, and accurate to no more than about 30 feet on either side of the line shown on the map. The 1937 aerial photographs are the primary data set for interpreting the surficial geologic deposits because: (1) they are the oldest high-quality images available and pre-date much of the cultivation and landscape alteration within present-day Sutter County (Figure 2); and, (2) because these data represent a close approximation to the surficial deposits that were likely present at the ground surface prior to construction of the levees. The 1937 photographs generally were taken in later summer or early autumn (i.e., August). By 1937, the area had experienced moderate cultivation that locally obscures geomorphic conditions. However, integration of data from the 1937 photographs, old and recent topography, existing geologic maps, existing soil surveys and historical documents provides sufficient information to delineate many of the pre-historical and historical surficial deposits in detail. Taken together, these data provide key insights to the geomorphic processes and resulting deposits that may affect levee underseepage.

Additional floodplain deposition may have occurred after 1937, due to flood overflows, levee overtopping, or localized levee failure. A time series analysis that interprets successive aerial photographs taken after major flood events (i.e., 1955) or known local levee failures (i.e., 1986) may reveal additional information on surficial deposits in the Wadsworth Canal area. However, such analyses are beyond the scope of this project. The data and interpretations presented herein address the primary goal of characterizing the type and distribution of deposits likely present directly beneath the project levees.

1.1 Report Preparation Quality Control

The surficial geologic map data and geomorphic interpretations presented in this memorandum were subject to quality control and quality assurance procedures as required by the Levee Geotechnical Evaluation Project Management Plan (PMP). The surficial geologic map data developed by this study were reviewed for accuracy and completeness through an internal review and an independent technical review by Dr. Janet Sowers of WLA. Results of QA/QC review were documented using PMP Exhibit 2.2-3 (Independent Technical Review Report) and are kept on file according filing control plan. Subsurface data shown on diagrams were provided as draft information, and were not verified for accuracy or completeness by this study.

2.0 Geologic Setting

The Wadsworth Canal (WC) study area is southeast of the Sutter Buttes, a presently in-active and dissected rhyolitic and andesitic volcanic neck, and between the Sacrametno River to the west and the Feather River to the east (Figure 1). The WC levee addressed in this study borders the southeastern side of Wadsworth Canal from just north of Butte House Road to the eastern Sutter Bypass levee. The WC levee trends northeast-southwest, and ties in to the eastern Sutter Bypass levee (Figure 1).

The WC levee lies northeast of Sutter Basin, a low-lying area east of the Sacramento River where overflow and floodwaters produce a seasonally marshy area. Except for the Sutter Buttes, the land regional surface is nearly flat, and along the WC area gently slopes southwest at an elevation of about 40 to 50 feet. Construction of the WC levee was completed by 1924, and was subsequently enlarged in 1942 (DWR, 1976). Prior to cultural modification, surface water runoff in the WC area was delivered to the Sutter Basin via intermittent, meandering creeks and sloughs from the northern Central Valley, including: Snake River, Snake Slough, Little Blue Creek, and ephemeral channels emanating from the eastern side of Sutter Buttes. Presently, many of the natural drainages and channels have been replaced by linear ditches, agricultural drains, and canals (Figure 2).

3.0 Surficial Geologic Mapping

Published surficial geologic maps within the WC study area generalized the surficial deposits primarily as Quaternary basin deposits, with localized units of Quaternary alluvium (map unit Qa) and Quaternary Modesto Formation (lower member, map unit Qml) (Helley and Harwood, 1985). These map units were delineated by Helley and Harwood (1985) at a regional scale (i.e., 1:62,500). The current analysis of the WC uses this existing geologic framework as a basis for more detailed mapping of late Holocene alluvium and geomorphic features (Plate 1). The surficial geologic map units in the Wadsworth Canal study area are described below, in order from oldest to youngest.

The oldest map unit exposed in the study area is the Pliocene-Pleistocene tuff breccia (map unit QTm). This rock primarily comprises a peripheral topographic ring around the relatively high relief Sutter Buttes, and consists of consolidated coarse material derived from the volcanic rocks of the Buttes. This bedrock is exposed in the northwest corner of the WC map area (plate 1).

The Quaternary Riverbank Formation (lower and upper members) is exposed at the ground surface adjacent to the tuff breccia (map unit Qrl and Qru, Plate 1). This map unit does not directly underlie the project levees in this study area, but is present in the shallow subsurface as alluvial-fan deposits derived from the Sutter Buttes during the middle Pleistocene (about 400,000 to 200,000 years ago). The Riverbank Formation is semi-consolidated, and the top of the formation is marked by a hardpan (or, duripan) layer that is a product of soil-forming processes over substantial geologic time. This hardpan layer reflects an ancient land surface that is now buried by younger deposits. In WC area, the upper Riverbank formation is associated with the Sutter clay (Strahorn, et al., 1911), and Marcum clay loam with “siltstone” hardpan (Lytle, 1988).

The late Pleistocene Modesto Formation is exposed at the surface as alluvial-fan deposits emanating from southwestern Sutter Buttes, and is younger than, and inset into, the Riverbank Formation (Plate 1). This unit is divided into two members, a lower (older) unit that is about 42,000 to 29,000 years old (map unit Qml), and an upper member that is about 24,000 to 12,000 years old (map unit Qmu) (Helley and Harwood, 1985). The upper member in the map area is associated with sub-linear low ridges to the east of the WC that have not been completely covered by basin deposits. The Modesto Formation is locally associated with the Sutter sandy loam (Strahorn, et al., 1911), and the Olashes sandy loam (Lytle, et al., 1988); the sand consisting of volcanic lithologies indicating derivation from Sutter Buttes parent material. The latest Pleistocene Modesto Formation, in general, consists of unconsolidated sand, silt, and clay, and is associated with a moderate amount of secondary (pedogenic) clay accumulation that may form laterally continuous zones of low hydraulic conductivity.

Holocene deposits (less than 11,000 years old) in the WC map area consist of basin and alluvial deposits (Qb of Helley and Harwood [1985]; map unit Qn, Plate 1). These widespread basin deposits, about 4 to 8 feet thick, overlie the Modesto Formation. The soils developed on the basin deposits are generally the Gridley clay loam and Oswald clay (Stahorn et al., 1911; Lytle, et al., 1988), immature soils with fine-grained textures. Undifferentiated Quaternary alluvium (map unit Qa) is present near the western margin of the map area, deposited by pre-historic Butte Creek. Holocene alluvium is mapped at the surface as alluvial-fan deposits emanating from southwestern Sutter Buttes, and is younger than, and locally overlies the upper Modesto Formation. These deposits likely consist of poorly sorted mixtures of fine gravel, sand, and silt derived from the volcanic rocks of the Buttes. The Quaternary marsh deposits (map unit Qs, Plate 1) are present between the levees of the Sutter Bypass, and consist of fine grained deposits that are differentiated from basin deposits by generally being underwater or having standing water at the time when the 1937 photographs were taken.

Holocene alluvial channels (map unit Hch, Plate 1) are mapped as a network of moderately sinuous channels with southwesterly orientations. These channels appear to be mostly filled in with sediment on the 1937 photographs, and are not expressed as strong topographic lows in the ground surface. Many of these channels extend beyond, and therefore cross beneath, the eastern Sutter Bypass levee and WC levee (Plate 1). The infilling material in the basal portions of the channel consists of relatively loose, coarse material (i.e., sand), which fines upward into fine-grained, silt and clay. The channel deposits are tentatively associated with the Liveoak series, sandy clay loam soil (Lytle, et al., 1988).

Localized deposits related to the Holocene alluvial channels are in-stream bars (map unit Hb) that typically occur in the medial portions of the channels, and distributary fans (map unit Hdf) that occur where the channel morphology tapers out and the channel has deposited sediment on the basin floor. These two types of deposits are uncommon in the study area, and have been mapped only distant from the WC levee.

Historical alluvial channels (map unit Rch, Plate 1) also are mapped as a network of moderately sinuous channels that have southwesterly orientations toward Sutter Basin. The term "historical" is applied to deposits that are estimated to be less than 150 years old. The historical channels are differentiated from the slightly older Holocene channels on the basis of cross-cutting relationships, relative degree of geomorphic expression, and correlation with mapped creek positions on the 1911 USGS topographic map. The Wadsworth Canal levee overlies the former locations of these alluvial channels in several locations throughout its length (Plate 1).

4.0 Conceptual Geomorphic Model

Based on synthesis of surficial geologic mapping, early topographic maps, soil surveys, geologic maps, and review of readily available subsurface geotechnical information, this section presents a preliminary conceptual model describing general relationships among surface and subsurface deposits in the Wadsworth Canal area. This conceptual model provides a consistent basis for understanding the type and distribution of surficial geologic deposits, primary geomorphic processes, and shallow subsurface stratigraphy in the area.

The geologic deposits present at the surface and in the shallow subsurface are derived from three general source areas: (1) material eroded from the Sutter Buttes and transported to the adjacent low-lying basin floor forming modest alluvial fans (i.e. Riverbank and Modesto Formations); (2) material deposited on the basin floor as fine silt and clay settled from standing or slow moving floodwaters of large rivers (i.e., basin deposits); and, (3) material transported to the basin by the ephemeral creeks and sloughs that traversed the valley floor prior to present day modification (i.e., channel fill).

The WC project levee trends southwest, and is primarily underlain by clayey basin deposits with some silt and sand (Plate 1, Figure 3). The basin deposits rest directly on the upper Modesto Formation, the upper boundary of which is characterized by a clay hardpan horizon associated with a buried soil. The hard pan layer is generally observed as a very stiff to hard, lean to fat clay, 10YR ¾ colors (Munsell color notation) associated with locally increased density (i.e., blow counts, CPT tip resistance), and likely very low permeability. Thus, the upper Modesto Formation mapped in northwest potion of the map area extends below ground, and dips southeasterly beneath the project levee in the shallow subsurface.

Fine-grained basin deposits overlie the upper Modesto Formation near the WC levees (Figure 3). These deposits accumulated on the valley floor over geologic time resulting from flooding of the major rivers (i.e., Sacramento and/or Feather Rivers), tributaries draining Sutter Buttes, and sheetwash from the generally flat valley floor. This resulted in inundation of the basin with standing water, and subsequent settlement of silt and clay from suspension. The thickness of the basin deposits is about 4 to 8 feet, but locally may be thicker. Review of available Phase 1 and other existing geotechnical data (i.e., Chambers 2002) indicate medium stiff to very stiff relative density of the basin deposits. However, there is a substantial lateral and vertical variability in the hardness properties of the basin deposits.

Laterally cross-cutting, and vertically inset into the basin deposits, are the Holocene and Historical channel deposits (map units Hch and Rch, Plate 1). These southwest-trending alluvial channel deposits locally underlie the WC levee, and thus result in local differences in material textures beneath the levee (Figure 3). Field reconnaissance on June 22, 2007 reveals that the topographic expression of these channels has been obliterated by cultivation. However, sub-linear to curvilinear differences in ground color (i.e., darker strips) were observed in the cultivated fields in areas that potentially correlate with mapped channels, suggesting a contrast in materials in the shallow subsurface. Review of subsurface geotechnical data indicate that the channel fill deposits include a lower channel fill consisting of relatively loose, coarser material (i.e., sand), fining upward and grading into fine-grained silt and clay. Many of these channels extend across, and therefore continue beneath, the WC levees (Plate 1, Figure 3).

Figure 3 illustrates the relationships between the surficial channels, basin deposits, and shallow stratigraphy that underlie the WC project levee, wherein dense, semi-consolidated Pleistocene deposits are overlain by a layer of fine-grained basin deposits, locally cut by alluvial channel deposits.

5.0 Applications to the Urban Levee Project

Based on synthesis of the surficial geologic map with preliminary Phase 1 boring and cone penetrometer (CPT) data, and historical geotechnical subsurface exploration data (i.e., Chambers, 2002), the WC levee is underlain by relatively young fine-grained clay and sandy clay deposits that are laterally interrupted by local coarser channel fill deposits (Figure 3). Mud rotary borehole WSEWWC-002B penetrates a mapped surficial channel unit (Figure 3, Plate 1), and indicates the channel fill is silty sand that grades upward into clay, with an uncorrected SPT blow count of 5 blows per foot. This suggests locally loose and unconsolidated, and therefore likely permeable, material in the shallow subsurface. Initial review of subsurface boring profiles completed along the eastern landside of the Wadsworth Canal near the tie-in to the Sutter Bypass levee (Chambers, 2002) also shows relatively loose and soft sandy deposits (i.e., blow counts of 0 to 5) that are overlain by a layer of medium stiff clay-rich material.

Synthesis of the surficial mapping and geotechnical data indicate that subsurface stratigraphy the WC area locally may be conducive to levee underseepage. Shallow strata typically include denser and probably semi-cemented material (i.e., Modesto Formation) that likely contains a low-permeability hardpan horizon. The hardpan may or may not be laterally continuous, depending on post-depositional soil formation and erosional processes. The Modesto formation is overlain by about 4 to 6 feet of medium stiff to stiff clay (i.e., basin deposits). Surficial mapping indicates that the basin materials locally are cross-cut by relatively loose, sandy channel deposits; subsurface geotechnical data show lateral and vertical variations in texture and density that are probably related to buried channel deposits. Therefore, this shallow subsurface stratigraphy may promote levee underseepage along certain areas of the WC project levees where geologically young, loose, sandy channel material lies between the dense Pleistocene deposits and relatively stiff, low-permeability clay-rich surface “blanket” layer.

Lateral and vertical variability in the shallow subsurface deposits has resulted from past geomorphic processes. The conceptual subsurface stratigraphic framework suggests that stratigraphic relationships may promote localized levee underseepage, given certain hydraulic conditions. Further spatial analyses of the surficial geologic mapping and subsurface geotechnical exploration data are needed to better constrain and characterize areas that are most susceptible to underseepage in the study area.

6.0 Limitations

This geomorphic assessment and associated data interpretation have been performed in accordance with the standard of care commonly used as the state-of-practice in the geologic engineering profession. Standard of care is defined as the ordinary diligence exercised by fellow practitioners in this geographic area performing the same services under similar circumstances during the same time period.

Discussions of surface and subsurface conditions summarized in this technical memorandum are based on geologic interpretations of subsurface soil data at limited exploration locations available to this assessment through July of 2007. Variations in subsurface conditions may exist between exploration locations, and the project team may not be able to identify all adverse conditions in the levee and its foundation. This memorandum is for the use and benefit of DWR. Use by any other party is at their own discretion and risk.

7.0 References

California Department of Water Resources (DWR), Northern District, 1976, "Sutter Bypass Study"

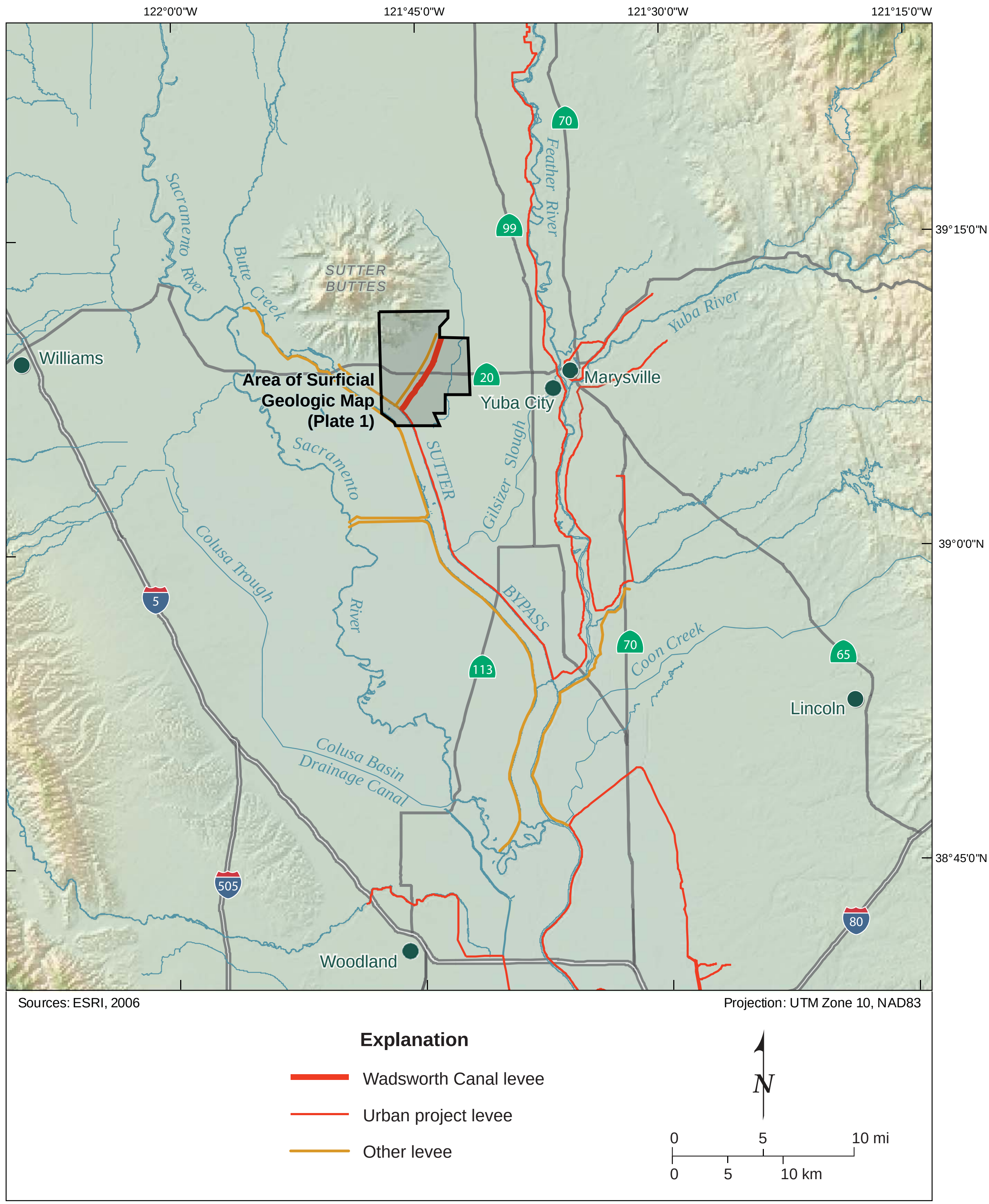
Chambers, J., 2002, US Army Corps of Engineers, Geotechnical Branch, Soil Design Section, "SAC-18 Wadsworth Canal – Dean Property Site"

Helley, E.J., and Harwood, D.S., 1985, Geologic map of the late Cenozoic deposits of the Sacramento Valley and Northern Sierran foothills, California; 1:62,500, USGS Map File MF-1790

Lytle, D.J., Kurowski, R.G., Whiting, M.L., Vinson, E.N., Vonich, P.W., Hansen, R.W., 1988, Soil Survey of Sutter County, California, 1:24,000, USDA Soil Conservation Service

Strahorn, A.T., Mackie, W.W., Holmes, L.C., Westover, H.L., Van Duyne, C., 1911, Soil Survey of the Marysville Area, California; 1:62,500, USDA Bureau of Soils

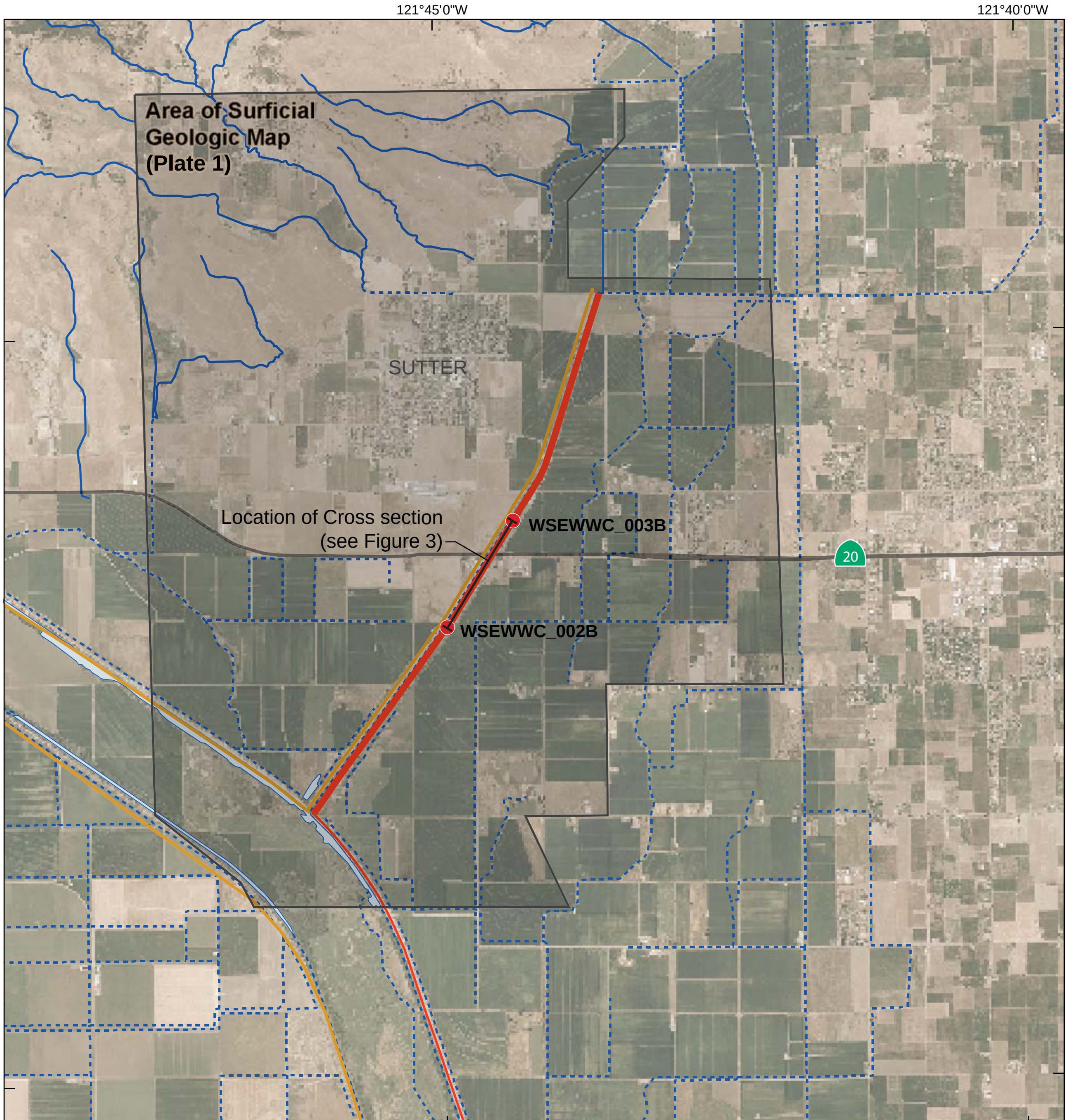
USGS, Sutter topographic quadrangle, surveyed 1909, published 1911; map scale 1:31,680, five foot contour interval.



Map of Northern Central Valley, California

DWR URBAN LEVEE PROJECT

Figure 1



Sources: ESRI, 2006

Projection: UTM Zone 10, NAD83

Explanation

- Creek, slough
- Canal, drain
- Wadsworth Canal Urban Project levee
- Other Urban Project levee
- Other levee

N

0 1 2 mi

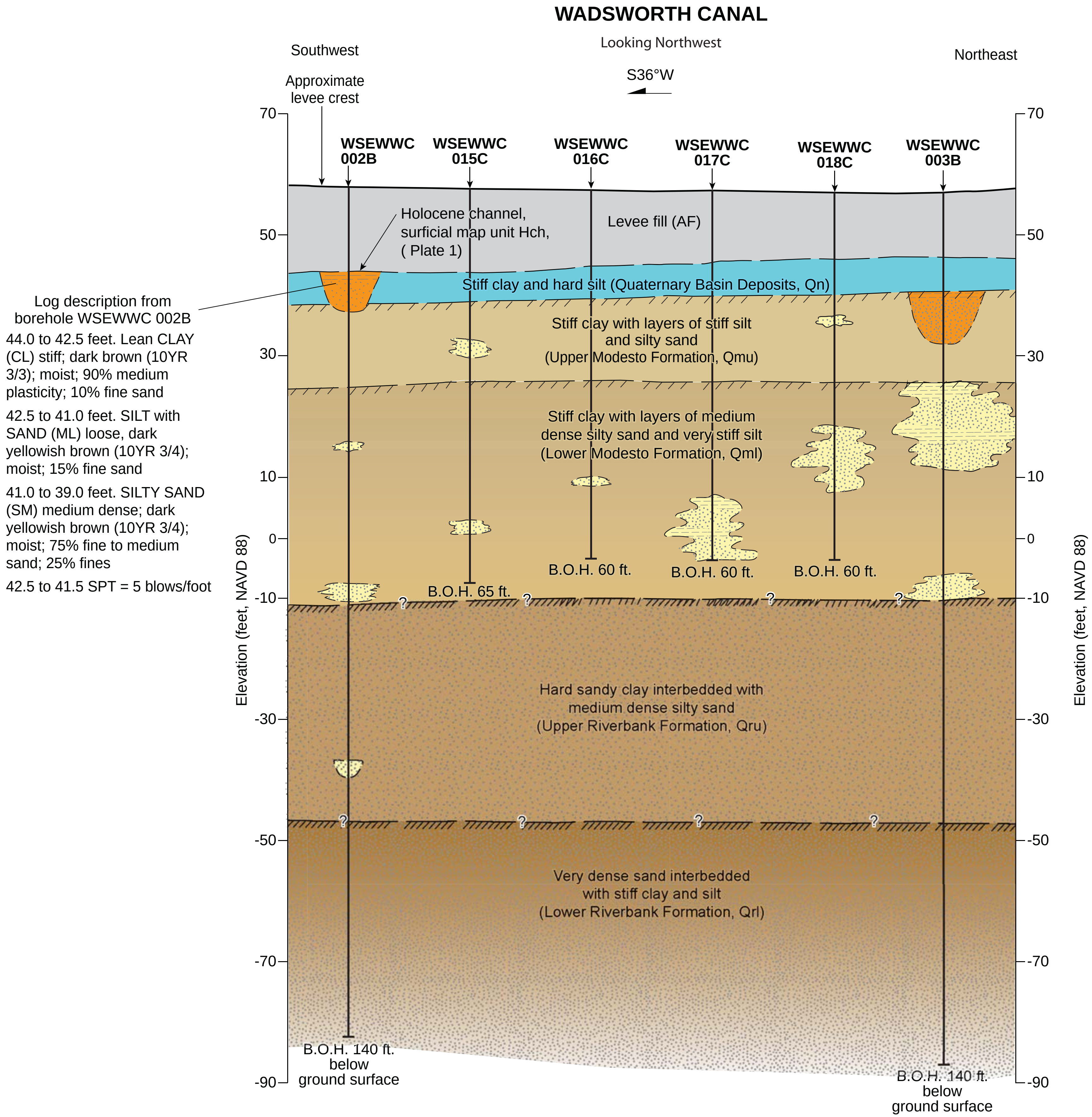
0 1 2 km

WLA

Sutter Bypass and Wadsworth Canal

DWR URBAN LEVEE PROJECT

Figure 2



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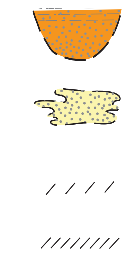
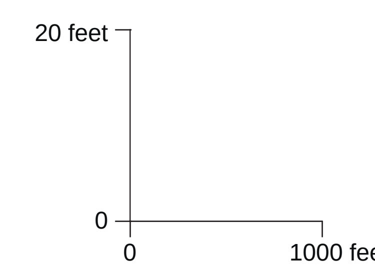


- Channel identified on surficial geologic map or as fining upward sequence of sediments in boreholes
- Localized sand and gravel; possible channel; interpreted from suburface borehole data
- Moderate paleosol (hardpan)
- Strong paleosol (hardpan)

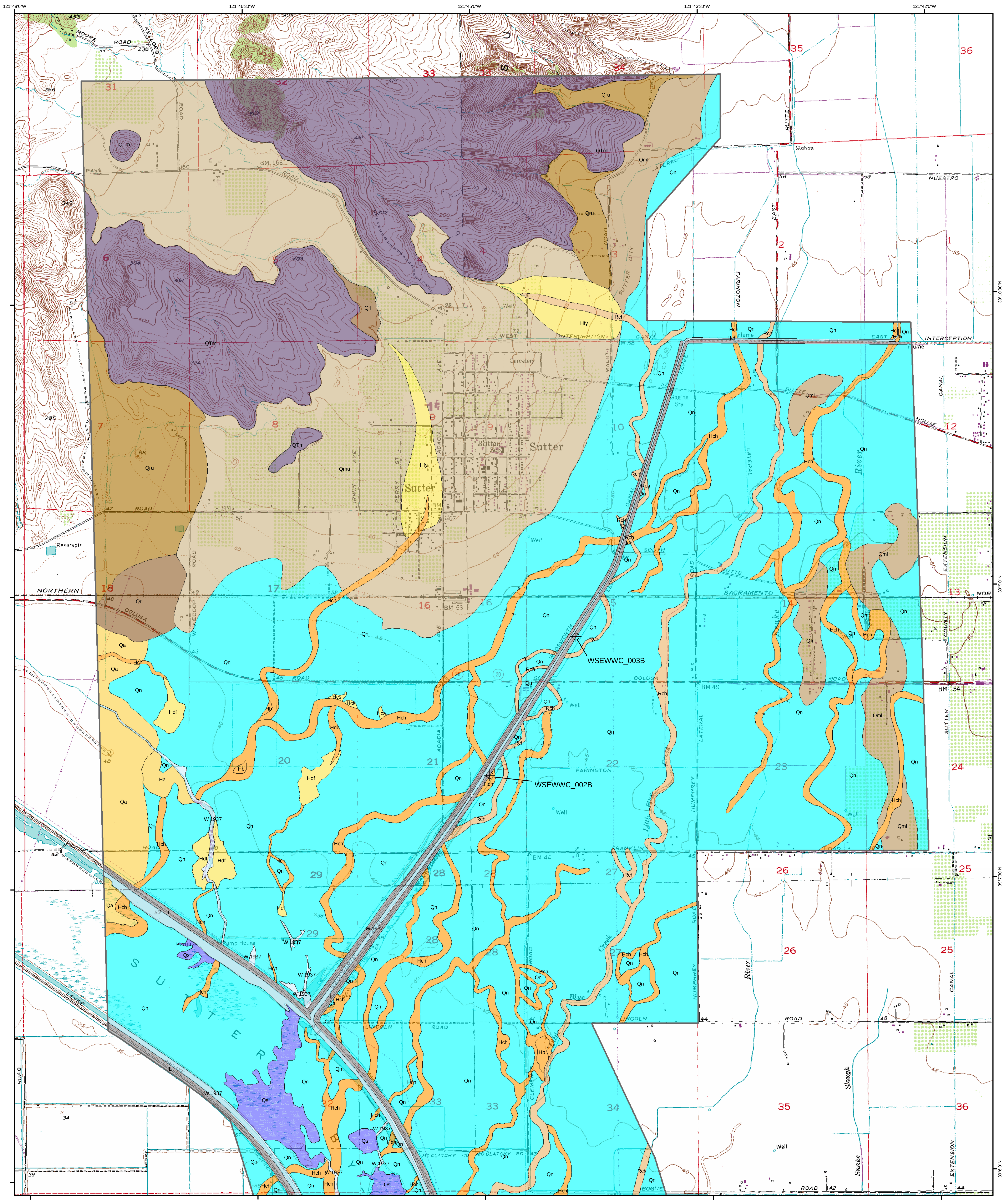
Notes:
1. Borehole ground elevation values from Engeo, Inc. draft borehole logs as estimated from map (NAVD 88). Absolute elevations of geologic contacts could change if reported ground elevations of boreholes are revised.
2. CPT borehole surface elevations are approximate, placed on projected ground surface between continuous boreholes WSEWWC-002B and 003B.
3. All depths (vertical axis) shown as elevation values (NAVD88), as shown on Engeo, Inc. borehole logs.
4. Bottom of hole (B.O.H.) values shown as total depth below ground surface.
5. Borehole names and and horizontal distance shown above (from Engeo logs and location maps). Geologic relations could change if borehole locations are revised.
6. Drilling method indicated as last letter in borehole name:
   B = Mud Rotary borehole with SPT
   C = Cone Penetrometer Test
7. See Figure 2 for location of cross section.



Scale

Vertical exaggeration 50X

Conceptual Cross Section along Eastern Levee Crest Wadsworth Canal



Explanation

Geologic contact; dashed where approximate, dotted where concealed, queried where uncertain; solid contacts have a resolution no better than about 30'.

WSEWWC_003B — Geotechnical borehole, approximately located.

W — Water visible on 1937 aerial photography.

Geologic Units

HISTORICAL

- AF — Artificial fill; visible on 1937 aerial photography.
- Rch — Channel deposits; sorted sands and silty sand; fining upward.

HOLOCENE

- Hcs — Crevasse splay deposits; fine to coarse sand, silt and clay.
- Hdc — Distributary channels, sand, silt, and clay.
- Hdf — Distributary fan deposits; sand, silt and clay.
- Ha — Alluvial deposits; undifferentiated; sand, silt, and minor lenses of gravel; under cultivation in 1937.
- Hch — Channel deposits; sorted sands and silts; fining upward.
- Hb — Channel bar deposits; fine sand, and silt deposited in or along channel lateral margins.
- Hfy — Alluvial fan deposits, well graded gravel, sand, silt and clay; volcanic lithologies.
- Qa — Alluvial deposits, undifferentiated; sand, silt, and minor lenses of gravel; under cultivation in 1937.
- Qn — Basin deposits; fine sand, silt and clay, dark yellow to dark yellowish brown, under cultivation in 1937.
- Qs — Marsh deposits; silt and clay, likely organic-rich; perennially or seasonally submerged on 1937 photography.

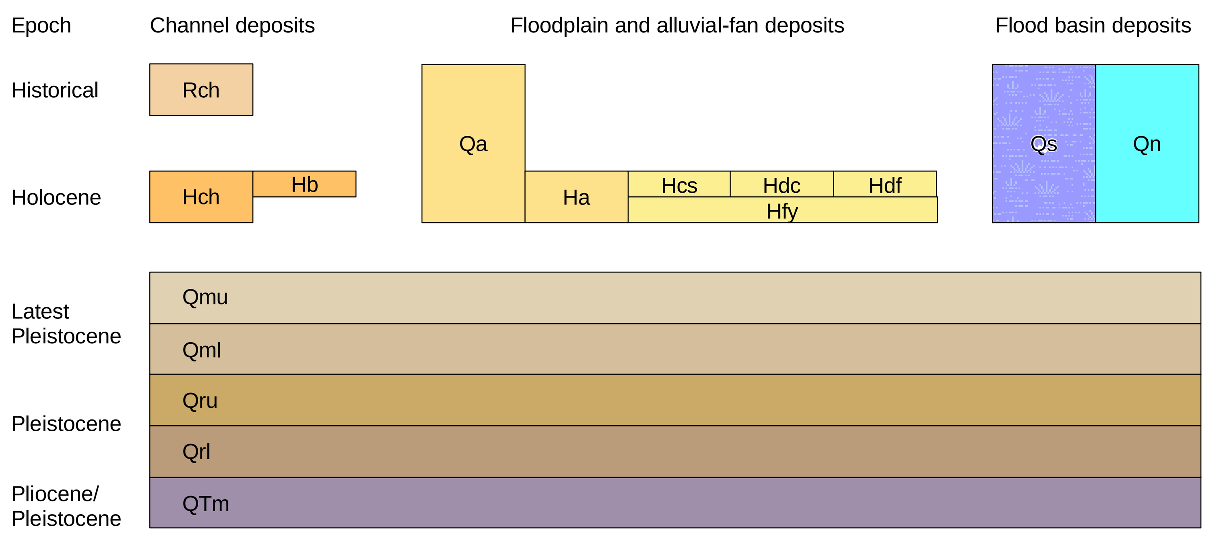
PLEISTOCENE

- Qmu — Modesto Formation; upper member; unconsolidated to semi-consolidated gravel, sand, silt, and clay.
- Qml — Modesto Formation; lower member; unconsolidated gravel, sand, silt and clay.
- Qru — Riverbank Formation; upper member, semi-consolidated to consolidated gravel, sand, silt and minor clay.
- Qrl — Riverbank Formation; lower member; consolidated gravel, sand, silt, and clay, generally associated with strong duripan horizon.

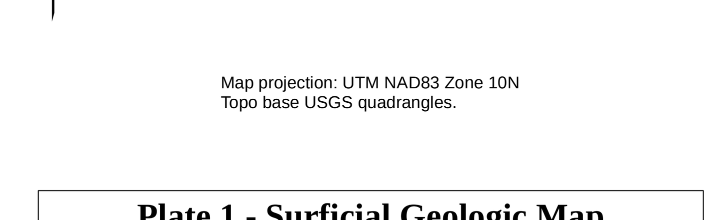
PLIOCENE / PLEISTOCENE

- QTm — Tuff Breccia; Volcanic tuff breccia (andesitic and rhyolitic) from Sutter Buttes, latest Pliocene.

Stratigraphic Correlation Chart



1:20,000



Map projection: UTM NAD83 Zone 10N
Topo base USGS quadrangles.

Plate 1 - Surficial Geologic Map of the Wadsworth Canal Area

WILLIAM LETTIS & ASSOCIATES, INC.
Walnut Creek, CA

Sutter_MGT_Plate1_Wadsworth.mxd 09/04/2009

Part C.3

URS Supplemental Geotechnical Data Report (2010), Appendix O, Volume 3

APPENDIX O

Geomorphology Report

WILLIAM LETTIS & ASSOCIATES, INC.
1777 Botelho Drive, Suite 262, Walnut Creek, California 94596
tel (925) 256-6070 fax (925) 256-6076

September 8, 2009

Mr. Juan Vargas
URS Corporation
2870 Gateway Oaks Drive, Suite 150
Sacramento, CA 95833

RE: Surficial geologic mapping and geomorphic assessment, California Department of Water Resources Urban Levees Project, Southern Feather River, Sutter County, California

Dear Mr. Vargas:

This memorandum presents the surficial geologic mapping and preliminary geomorphic assessment of the southern Feather River study area, for the California Department of Water Resources (DWR) Urban Levees Project geotechnical characterization. The goal of this mapping and geomorphic assessment is to provide information on the type and distribution of surface and shallow subsurface deposits that likely underlie the project levees along the western bank of the Feather River. The purpose of this study is to develop spatially-continuous geologic data and a conceptual model that provides a framework for stratigraphic interpretations between widely-spaced subsurface explorations. A primary goal is to provide a geologic framework for the geotechnical assessment of potential levee underseepage. This memo presents the technical approach, surficial geologic map, conceptual geomorphic model, and initial results based on map analysis and preliminary review of Phase 1 geotechnical data.

We appreciated the opportunity to provide these geomorphic and geologic data and preliminary interpretations of the shallow stratigraphic conditions in the southern Feather River study area. Please do not hesitate to call either of the undersigned if there are any questions or comments.

Respectfully,

WILLIAM LETTIS & ASSOCIATES, INC.

Justin Pearce

Justin Pearce, C.E.G. 2421
Senior Geologist

Ashley R. Streig

Ashley Streig
Senior Staff Geologist

Keith Kelson

Keith Kelson, C.E.G. 1610
Principal Geologist

1.0 Approach

The approach to developing a surficial geologic map of the southern Feather River project area (Figure 1, Plate 1) consisted of analysis of the following data: Aerial photography (black and white stereo-pairs taken in 1937, ~1:20,000-scale); early USGS topographic maps (i.e., 1911); published surficial geologic maps (Helley and Harwood, 1985); early and modern soil survey maps (Strahorn et al., 1909; Lytle, et al., 1988); and other maps and documents (Busacca et al., 1989). Synthesis of these data allow for the development of a detailed surficial geologic map that provides an initial understanding of primary geomorphic processes that have acted in the study area during recent and historical geologic time. Through this mapping, primary geomorphic features and associated surficial geologic deposits are identified, such as abandoned paleochannels, channel deposits, floodplain deposits, basin deposits and other features commonly associated with surficial deposits with large active river systems. Knowledge of fluvial processes and the ability to recognize depositional environments in the geologic record are key to identifying locations along levees where underseepage is most likely to occur (Llopis et al., 2007).

The surficial geologic map was developed at the nominal scale of the aerial photography (1:20,000). This scale establishes the resolution of the map (Plate 1), such that analysis of the map data at a more detailed scale than 1:20,000 may introduce uncertainties beyond the original resolution of the data. The map unit boundaries shown on the surficial geologic map should be considered approximate, and accurate within 30 feet on either side of the line shown on the map. The 1937 aerial photographs are the primary data set for interpreting the surficial geologic deposits because: (1) they are the oldest high-quality images that pre-date much of the urbanization and landscape alteration within present-day Sutter County (i.e. Figure 2); and, (2) these data represent a close approximation to the surficial deposits that were likely present at the ground surface prior to the construction of the levees. The 1937 photographs generally were taken in late summer or early autumn (i.e., August). By 1937, the area had experienced moderate cultivation that locally obscures geomorphic conditions. However, integration of data from the 1937 photography, old and recent topographic maps, geologic maps, soil surveys and historical documents provides sufficient information to delineate many of the pre-historical and historical surficial deposits in detail. Taken together, these data provide key insights to the characteristics of shallow deposits beneath the levees, as well as the geomorphic processes responsible for their distribution.

Additional floodplain deposition may have occurred after 1937, due to flood overflows, levee overtopping, or localized levee failure. A time series analysis that interprets successive aerial photographs taken after major flood events (i.e., USDA, black and white stereo-pairs taken in 1958, ~1:20,000-scale) or known local levee failures (i.e., 1986) may reveal additional information on surficial deposits in the southern Feather River area. Such analyses are beyond the scope of this study. The data and interpretations presented herein address the primary goal of characterizing the type and distribution of deposits likely present directly beneath the project levees.

1.1 Report Preparation Quality Control

The surficial geologic map data and geomorphic interpretations presented in this memorandum were subject to quality control and quality assurance procedures as required by the Levee Geotechnical Evaluation Project Management Plan (PMP). The surficial geologic map data developed by this study were reviewed for accuracy and completeness through an internal review and an independent technical review by Dr. Janet Sowers of WLA. Results of QA/QC review were documented using PMP Exhibit 2.2-3 (Independent Technical Review Report) and are kept on file according filing control plan. Subsurface data shown on diagrams were provided as draft information, and were not verified for accuracy or completeness by this study.

2.0 Geologic Setting

The southern Feather River study area lies in the Central Sacramento Valley, between the Coast Ranges to the west and the Sierra Nevada foothills to the east. Feather River drains the western slope of the Sierra Nevada, and emerges from the mountains south of the Thermalito Afterbay (Figure 1). The river flows southward from the Thermalito Afterbay, over middle-to late Pleistocene dissected alluvium derived from the Sierra Nevada. The regional land surface is nearly flat, with a gentle west-southwest slope that flattens out south of the Sutter Buttes, in Sutter Basin. The Feather River is entrenched into middle to late Pleistocene semi-consolidated sediments. Holocene alluvium deposited by the Feather River is present between the present-day levees, inset to the older formations, as well as on the western floodplain as subdued natural levees. The river trends roughly south until its confluence with the Bear River, where it curves
to the southwest (Figure 1). The Feather River lies east of, and is a tributary to the Sacramento River, converging near the town of Nicolaus (Figure 1). A primary influence on the historic processes in the river system was the hydraulic mining that began in the 1850's. Mining occurred through the early 1900's in the Feather, Yuba and Bear River watersheds, and abruptly introduced large quantities of sediment, drastically changing the geomorphic characteristics of these river systems (DWR, 2004; Ellis, 1939). Aggradation within the stream channel was a primary response to the introduction of substantial mining debris (James, 1999), consequently young alluvial deposits are common throughout the study area.

3.0 Surficial Geologic Mapping

Previous geologic mapping in the study area along the Feather River and surrounding areas generalize the surficial deposits as: Quaternary Alluvium (Qa) and Quaternary stream channel deposits (Qsc) within and proximal to the modern Feather River channel, (Helley and Harwood, 1985). These map units are considered Holocene age (less than 11,000 years old). Late Quaternary Modesto Formation (Qmu, Qml) is mapped along the western margin of the floodplain. These map units were delineated by Helley and Harwood (1985) at a regional scale (i.e., 1:62,500). The current analysis of the Feather River uses this geologic framework as a basis for more detailed mapping of late Holocene alluvium and geomorphic features (Plate 1).

The surficial geologic map units within the southern Feather River study area are described below, in order from oldest to youngest. Surficial geologic mapping for this study subdivides these map units and delineates individual deposits based on relative age and depositional process or environment (Plate 1). The map units depicted on Plate 1 are based primarily on analysis of 1937-vintage photography, and thus the map essentially is a "snapshot" of geologic conditions at this time.

The oldest unit exposed along the Feather River is the lower member of the Riverbank Formation (Qrl) of Helley and Harwood (1985). This unit is a highly dissected alluvial surface with textures of weathered gravel, sand and silt with strong soil-profile development. The Riverbank Formation is semi-consolidated, and is associated with the presence of a well-developed hardpan (or, duripan) layer that is a product of soil-forming processes over substantial geologic time. This hardpan layer reflects an ancient land surface that locally is buried by younger deposits. The Riverbank Formation is late to middle Pleistocene in age, and is estimated to be 130,000 to 450,000 yrs old (Helley and Harwood, 1985). The upper member is unconsolidated dark brown to red alluvium consisting of gravel, sand, silt and minor clay (Busacca et al., 1989, Helley and Harwood, 1985).

The Modesto Formation is divided into two members, a lower (older) unit that is latest Pleistocene in age (about 29,000 to 49,000 years old), and consists of unconsolidated slightly weathered gravel, sand, silt and clay. The upper member, a younger unit, is latest Pleistocene age (circa 12,000 to 26,000 years old) (Helley and Harwood, 1985). This unit (Qmu) is composed of sand, silt, and some gravel, comprising river channel and floodplain deposits, and is associated with a moderate amount of secondary (pedogenic) clay accumulation. This clay-rich horizon may form laterally continuous zones of low hydraulic conductivity, and may extend across boundaries between coarse and fine-grained strata within the latest Pleistocene alluvium. Soils on the Modesto Formation deposits include the Gridley loam of Strahorn et al. (1909) and the Conejo complex of Lytle et al. (1988).

Latest Holocene deposits overlie or are inset into the Modesto Formation, and are categorized as channel, floodplain, and basin deposits (Plate 1). Channel deposits include Holocene channels (Hch), distributary channels (Hdc), overflow channels (Hofc), sloughs (Hsl), in-stream or lateral bars (Hb), and meander scrolls (Hms). These deposits likely consist of fine to coarse sand, silty sand, and clayey sand, with trace fine gravel. Holocene channel deposits (Hch), which are present along Gilsizer Slough and the western floodplain as secondary channels, contain fining-upward sequences of sand, silt and clay. Overflow channels (Hofc) transport water across the land surface during high flow stages toward Sutter Basin. Networks of sloughs wander across the distal floodplain, and are likely filled with a fining-upward sequence of silt and clay (map unit Hsl). These deposits are associated with former channels, and generally are present landside (outboard) of the present-day human-made levees.

Holocene floodplain deposits include crevasse splays (Hcs), distributary fans (Hdf), and overbank deposits (Hob). Crevasse splays (Hcs) are sandy deposits that form from breaching of river banks or natural levees. Distributary fan deposits (Hdf) occur when water and velocity within a distributary channel decreases, can no longer transport its sediment load, and sediment is laid down on the floodplain. Overbank sediments are formed by localized overtopping of river banks or natural levees, subsequent deposition from shallow sheet flow or standing water. Basin deposits occur on the distal floodplain and include undifferentiated basin deposits (Qn), and marsh deposits (Qs). Basin and marsh deposits are present in the topographically low areas west of the present-day natural levees along the Feather River. These deposits consist of fine sand, silt, and clay laid down in a relatively low-energy depositional environment. Soils developed on these deposits are the Sacramento series silt loam, fine sandy loam, clay, Alamo clay loam adobe and Stockton clay adobe. Marsh deposits are generally saturated and are often underwater in the present-day environment. Undifferentiated Holocene and Quaternary alluvium (Ha and Qa, respectively) usually are proximal to the river channel, and this map unit is used in areas where geomorphic features are obscured or obliterated by historical (1937-era) agriculture or cultivation. The deposits within these agriculturally modified areas are assigned a relative age (Ha or Qa) based on overlapping and cross cutting relationships with the surrounding deposits as follows: Ha if the agriculture-modified area is mapped within or shown overlying Holocene deposits; or Qa where it is difficult to evaluate the surface age based on the nearby deposits. Soils associated with these, undifferentiated units (Qa) are the Sacramento silt loam and Sacramento fine sandy loam, (Strahorn et al., 1909), and the Columbia fine sandy loam of Lyle et al. (1988), which are weakly developed soils commonly developed on relatively young deposits.

Historical deposits mapped in the area include stream channel and floodplain deposits, as well as artificial fill deposits (L and SP) (Plate 1). Historical deposits are estimated to be less than 150 years old, dating from approximately 1800 to 1937. Historical stream channels (Rch), distributary channels (Rdc), and overflow channels (Rofc) within the floodplain are recently abandoned channels or reflect active channels with low water flow. Lateral bar deposits (Rb) and meander scrolls (Rms) are located adjacent to the present-day Feather River, and are generally present inboard (waterside) of the present-day Feather River levees. When the river overtops its banks, distributary channels (Rdc) and recent overflow channels (Rofc) transport water and sediment across the floodplain. These channel deposits likely consist of silt and sand with traces of gravel. The upper few feet of these deposits probably are filled with debris from upstream hydraulic mining activities. Historical sloughs transport low velocity water flow derived from distributary channels proximal to the Feather River onto the distal floodplain and into the Sutter Basin. Slough deposits (Rsl) likely consist of fining-upward silt and clay.

Historical flood plain deposits include crevasse splay (Rcs), distributary fan (Rdf), and overbank (Rob) deposits, which generally consist of a fining upward or episodic fining upward sequence of sand, silt, and clay. Historical overbank (Rob) deposits are slightly finer grained sand, silt, and clay deposited via sheet flow when the river is at flood-stage and overtops natural and artificial levees. These historical deposits are differentiated based on cross-cutting and superposition relationships relative to existing cultural deposits visible on the 1937 photographs. Historical alluvial deposits (Ra), generally located within the Feather River channel, consist of undifferentiated sand, silt, and minor lenses of gravel. Historical artificial fills (map units L and SP) are culturally-emplaced heterogeneous deposits, with varying amounts of clay, silt, sand, and gravel from local sources. These deposits include levee structures and canal levee systems (L), and some undifferentiated soil piles (SP), and are shown on the surficial geologic map where present and identifiable on the 1937 photography.

Mapping of historical and Holocene deposits shown on Plate 1 generally is consistent with early, less-detailed soil survey mapping along the western banks of the Feather River as areas of Gridley loam, Sacramento Series fine sand, sandy loam and silt loam soils (Strahorn et al., 1909). The Gridley loam occurs along the northern Feather River from Thermalito south to the confluence with the Bear River, and closely corresponds to the Modesto Formation of Helley and Harwood (1985). The relationship between the mapped surficial geologic units and the potential for underseepage is summarized below.

4.0 Geomorphic Conceptual Model

The preliminary conceptual model described here is based on general relationships among surface and subsurface geologic deposits along the Feather River, as described above and shown on Plate 1. This conceptual model provides a consistent basis for understanding the type and stratigraphy in the area.

Published geologic maps of the project area identify a complex series of westward aggrading alluvial fans and terraces derived from the Sierra Nevada, identified as the Riverbank and Modesto formations. The Riverbank Formation and Modesto Formation are semi-consolidated to unconsolidated deposits characterized by intraformational paleochannels and lateral and vertical stratigraphic complexity related to past fluvial processes and buried paleo-topography. The Riverbank Formation unconformably overlies the Laguna Formation, which is a deeply dissected alluvial surface (Busacca et al., 1989).

Subsurface deposits about 150 feet beneath the ground surface rest on a resistant volcanic tuff capped by interbedded alluvial gravel, sand and silt, interpreted as Pliocene-Pleistocene age Laguna Formation that represents a period of relatively stable landscape conditions (Helley and Harwood, 1985). The Laguna Formation is overlain by the Pleistocene Riverbank Formation, (very dense gravel deposits) that are, in turn, overlain by a medium dense sand and gravelly sand package of the latest Pleistocene Modesto Formation (Busacca et al., 1989). The upper member of the Modesto Formation is exposed at the ground surface adjacent to the western bank of the Feather River south of Marysville and Yuba City. The Modesto Formation is mantled by unconsolidated deposits of Holocene age that comprise most of the surficial geologic deposits along the western side of the Feather River (Plate 1).

Geomorphic evidence suggests that the Feather River system south of Yuba City may have been located west of its present course (Figure 3). The present-day Gilsizer Slough diverges from the modern Feather River directly north of Yuba City and trends southwestward toward the Sacramento River. Alluvial deposits of Gilsizer Slough are inset (i.e. incised) into the Modesto Formation from Yuba City southward. The ancestral Gilsizer Slough perhaps extended to as far as the Sacramento River (Figure 3), based on surficial mapping not included in this report, and inspection of topographic maps. The ancestral Gilsizer Slough deposits are related to discharges and sediment loads that were higher than present-day conditions, and perhaps is an ancestral course of the Feather River.

Surficial geologic deposits near the Yuba City airport indicate the Feather River occupied an intermediate position between ancestral and present locations. The river occupied an abandoned channel arm north of Shanghai Bend, located between Gilsizer Slough and the modern Feather River (Figure 3). From this point the river continued southward in nearly its present location. This paleochannel had a sharp, more exaggerated bend than the present-day channel at Shanghai Bend (Figure 2). The channel subsequently moved eastward, laterally backfilling and abandoning the meander above Shanghai Bend, and moved to the rivers' present location closer to Marysville. Today, Gilsizer Slough is a natural bypass for high water flow stages on the Feather River, in the area between Marysville and Yuba City (Ellis, 1939).

Surficial geologic mapping (Plate 1) shows differences in deposit type and distribution from north to south along the Feather River, which is associated with changes in watershed production of water and sediment, related geomorphic processes, soil profile development, and the underlying subsurface hardpan layer. These differences illustrate the diversity of past geomorphic processes along the river and, as a consequence, the type of geologic deposits at and near the ground surface. The surficial geologic map allows the delineation of reaches along the river within which geomorphic processes and their associated deposits appear to be relatively consistent.

Between Yuba City on the north to the confluence with the Sutter Bypass on the south, the southern Feather River consists of four major reaches, each having characteristic deposit types and distributions. The river reaches are numbered Southern Feather one through four (SF-I through SF-IV), sequentially from north to south (Plate 1, Figure 3). This report describes the surficial geologic characteristics of Reach SF-I, SF-II, SF-III and SF-IV of the southern part of the Feather River, extending from Yuba City, south to the confluence with the Sutter Bypass.

Reach SF-I, extends from the north end of Yuba City to the Yuba City airport, and is about 1.15 miles long (Plate 1, Figure 3). The Project levee along Reach SF-I trends roughly north-south, and overlies alluvial sediments deposited by the Feather River. In Yuba City the levee rests on Holocene deposits associated with Gilsizer Slough that are inset into the upper member of the Modesto Formation. The active Feather River channel is east of, and inset to these Holocene channel deposits (Figure 4).

The second reach of south Feather River project area, SF-II, extends from the Yuba City airport south to Shanghai Bend, and is about 2.9 miles long. Near the Yuba City airport, and south of the confluence of the Feather and Yuba Rivers, young channel deposits are inset against the Gilsizer Slough channel deposits (Plate 1). From the Yuba City airport, south to Epley Drive (about 1.5 miles), the levees overlie historical alluvium of mining debris origin, map unit Ra. From Epley Drive south to Shanghai Bend Road the levees (about 1.4 miles) overlie historical meander scrolls, map unit Rms, (Figure 2, Plate 1). The levee along this reach, SF-II, primarily overlies Holocene channel fill, historical alluvium and overbank deposits. These channels are likely filled with a fining-upward sequence of gravel, sand and silt, the upper few feet of these features are probably covered by a veneer of sediment derived from upstream hydraulic mining activities (Figure 4).

River Reach SF-III extends from Shanghai Bend on the north to just south of the confluence with Bear River, and is approximately 12 miles long (Plate 1). Along Reach SF-III, the active river floodplain is inset into the upper member of the Modesto Formation. Over geologic time, flooding has lead to the vertical accretion of overbank and crevasse splay deposits onto the Modesto Formation west of the Feather River. Overflow channels and related deposits (Rofc) are common along this reach of the river. Beginning at Shanghai Bend and continuing southward are seven overflow channels that range from approximately 100 to 200 feet wide. The Project levees overlie these channels in the area around Messick Road (Plate 1). A few overflow channels conduct water flow immediately landside of the levees, across a short distance between Shanghai Bend and Oswald Avenue, then converge with the Feather River. The overflow channels are slightly inset to the Modesto Formation, and based on borehole data from locations where these channels cross the Sutter Bypass, are probably 6 to 15 feet deep. These channels are likely filled with episodic fining upward sequences of silt, sand and gravel, representing multiple flood events on the Feather River. The upper few feet of these channels are probably filled with sediment from upstream historic hydraulic mining activities. The river channel widens considerably between Country Club Road (0.5 mile width) and Obanion Road (1 mile width), (Plate 1). Feather River meanders along the eastern edge of Abbott Lake, swings sharply southward into Star Bend, where the river is deflected eastward by a resistant knob of Modesto Formation (which forms Star Bend). Historical crevasse splay and overbank deposits overlie the Modesto Formation from Abbott Road to Star Bend Road, along the western edge of Abbot Lake (Figure 5). These crevasse splay deposits are likely filled with a fining-upward sequence of fine gravel, sand and silt, The upper few feet of these features are probably covered by a veneer of hydraulic mining sediment.

The southernmost reach, Reach SF-IV, extends from the area south of the confluence with the Bear River to the confluence of the Feather River and Sutter Bypass, and is roughly 4 miles long (Plate 1). The sediments underlying the levee along this reach are geomorphically complex, resulting from depositional convergence between the Feather River and Bear River. The Bear River channel deposits large amounts of sediment across the ground surface adjacent to the confluence. The Modesto and Riverbank Formations are exposed at the ground surface adjacent to natural levees immediately north of the Bear River confluence, and north of this reach (Plate 1). These formations are covered by historical alluvium, sourced from the Feather and Bear Rivers. Much of the historical activity along this reach is located near the levee at Laurel Avenue. Here, consisting eight distributary channels (Rdc), typically 90 feet wide but ranging from 45 to 190 feet wide, cross the floodplain in southwesterly orientations, terminating in geologically young distributary-fan sediments. These sediments, primarily consisting of fine to coarse sand and silt, probably were deposited as a result of increased sediment and water input contributed to the Feather River from the Bear River. Historically, the Feather River and the Bear River have aggraded from substantial mining debris input, thus reducing channel cross sectional area (i.e., James, 1999). This reduction of cross section area, coupled with the trajectory of flood flow from the Bear River watershed, resulted in water overtopping the Feather River channel banks, and depositing sediment onto the floodplain between the confluence of the Feather River and Sutter Bypass (Plate1).

5.0 Applications to the Urban Levee Project

Based on an initial analysis of surface geologic and geomorphic data, the levees bordering the western side of the Feather River from Yuba City to the Sutter Bypass, (Reaches SF-I, SF-II, SFIII and SF-IV) probably are underlain by a veneer of near-surface sandy deposits, or by buried channels that are inset into the Modesto Formation. The preliminary conceptual surface and subsurface geologic relationships as they relate to levee structures and potential underseepage along each reach of the river are described below. This study does not account for any existing seepage mitigation structures, i.e. slurry wall or cutoff wall, which may be present.

Reach SF-I contains the Gilsizer paleochannel deposits, this channel intersects the levees roughly 660 feet south of Lynn Way to Colusa Avenue (Plate 1). Along this length the levees are underlain by coarse channel deposits. These coarse grain deposits are likely laterally continuous and poorly consolidated and relatively highly permeable, and likely are susceptible to underseepage.

Levees along the reach SF-II are underlain by a Holocene paleochannel and historical meander scroll deposits (Figure 2, Plate 1). These deposits are coarse grained, laterally continuous and poorly consolidated, and likely are susceptible to underseepage. The presence of this paleochannel deposit suggests locally permeable material (channel fill) directly underlying the levees. Historical alluvium most likely of mining debris origin, blankets the Yuba City airport paleochannel and meander scroll deposits. The levees along this reach are underlain by a thick sequence of young, permeable alluvium of meander scroll deposits that are highly susceptible to seepage (Glynn and Kuszmaul, 2004).

Reach SF-III consists of coarse-grained avulsion deposits (overbank, crevasse splay and overflow channel deposits) overlying the Modesto Formation. Overflow channels (Rofc) are common along this reach, are relatively thin, slightly inset to the Modesto Formation and are filled with poorly consolidated sediments that may provide local pathways for underseepage. Individual shallow coarse deposits may be laterally discontinuous and may be separated by clayey interbeds (i.e. thin blankets). Local coarse deposits may be associated with higher likelihoods of levee underseepage. Deeper deposits probably consist of consolidated Modesto Formation with occasional small, but unconsolidated, overflow channel deposits incised into resistant strata.

Along Reach SF-IV the levee is underlain by laterally-continuous sandy deposits formed by distributary overbank fans and by the south flowing ancestral Feather River (Gilsizer Slough). These coarse-grained deposits likely are permeable and susceptible to underseepage. Near Laurel Avenue distributary channel deposits underlie the levees and may be relatively coarser than the surrounding alluvium.

6.0 Summary

Lateral and vertical variability in the shallow subsurface deposits has resulted from past geomorphic processes. Surficial geologic mapping along the south Feather River allows reach classifications within which conditions may be relatively consistent. The conceptual subsurface stratigraphic framework suggests that stratigraphic relationships may promote localized levee underseepage, given certain hydraulic conditions, particularly along reach SF-I and II. Further spatial analyses of the surficial geologic mapping and subsurface geotechnical exploration data are needed to better constrain and characterize areas that are most susceptible to underseepage in the study area.

7.0 Limitations

This geomorphic assessment and associated data interpretation have been performed in accordance with the standard of care commonly used as the state-of-practice in the geologic engineering profession. Standard of care is defined as the ordinary diligence exercised by fellow practitioners in this geographic area performing the same services under similar circumstances during the same time period.

Discussions of surface and subsurface conditions summarized in this technical memorandum are based on geologic interpretations of subsurface soil data at limited exploration locations available to this assessment through August of 2007. Variations in subsurface conditions may exist between exploration locations, and the project team may not be able to identify all adverse conditions in the levee and its foundation. This memorandum is for the use and benefit of DWR. Use by any other party is at their own discretion and risk.

8.0 References

Busacca, A.J, Singer, M.J., and Verosub, K.L., 1989, Late Cenozoic Stratigraphy of the Feather and Yuba Rivers Area, California, with a Section on Soil Development in Mixed Alluvium atHoncut Creek, USGS Bulletin 1590-G.

Department of Water Resources (DWR), 2004, SP-G2: Effects of Project Operations on Geomorphic Processes Downstream of Oroville Dam, Task 6 – Channel Meanders and Bank Erosion Monitoring, Oroville Facilities Relicensing FERC Project No. 2100, July.

Ellis, W.T., 1939, Memories: My Seventy-two Years in the Romantic County of Yuba, California (Memoirs of Marysville Levee Commissioner), p.103.

Helley, E.J., and Harwood, D.S., 1985, Geologic map of the late Cenozoic deposits of the Sacramento Valley and Northern Sierran foothills, California; 1:62,500, USGS Map File MF-1790.

Glynn, M.E., and Kuszmaul, J., 2004, Prediction of Piping Erosion Along Middle Mississippi River Levees – An Empirical Model; Technologies and Operational Innovations for Urban Watershed Networks Research Program; US Army Corps of Engineers, Engineer Research and Development Center, Geotechnical and Structures Laboratory publication ERDC/GSL TR-04-12.

James, A., 1999, Time and the Persistence of Alluvium: River Engineering, Fluvial Geomorphology, and Mining Sediment in California; Geomorphology, v. 31, p. 265 – 290.

Llopis, J.L., Smith, E.W., and North, R.E., 2007, Geophysical Surveys for Assessing Levee Foundation Conditions, Sacramento River Levees, Sacramento, CA; US Army Corps of Engineers, Engineer Research and Development Center, Geotechnical and Structures Laboratory publication ERDC/GSL TR-07-21, 61p.

Lytle, D.J., Kurowski, R.G., Whiting, M.L., Vinson, E.N., Vonich, P.W., Hansen, R.W., 1988, Soil Survey of Sutter County, California, 1:24,000, USDA Soil Conservation Service.

Strahorn, A.T., Mackie, W.W., Holmes, L.C., Westover, H.L., Van Duyne, C., 1909, Soil Survey of the Marysville Area, California; 1:62,500, USDA Bureau of Soils.

USGS, Gilsizer Slough topographic quadrangle, surveyed 1909, published 1911; map scale 1:31,680, five foot contour interval.

USGS, Marcuse topographic quadrangle, surveyed 1906, published 1910; map scale 1:31,680, five foot contour interval.

USGS, Nicolaus topographic quadrangle, surveyed 1908, published 1910; map scale 1:31,680, five foot contour interval.

USGS, Ostrom topographic quadrangle, surveyed 1909, published 1911; map scale 1:31,680, five foot contour interval.

USGS, Sutter topographic quadrangle, surveyed 1909, published 1911; map scale 1:31,680, five foot contour interval.

USGS, Yuba City topographic quadrangle, surveyed 1909, published 1911; map scale 1:31,680, five foot contour interval.

USGS, Gilsizer Slough topographic quadrangle, published 1952, photo revised 1973; map scale 1:24,000, five foot contour interval.

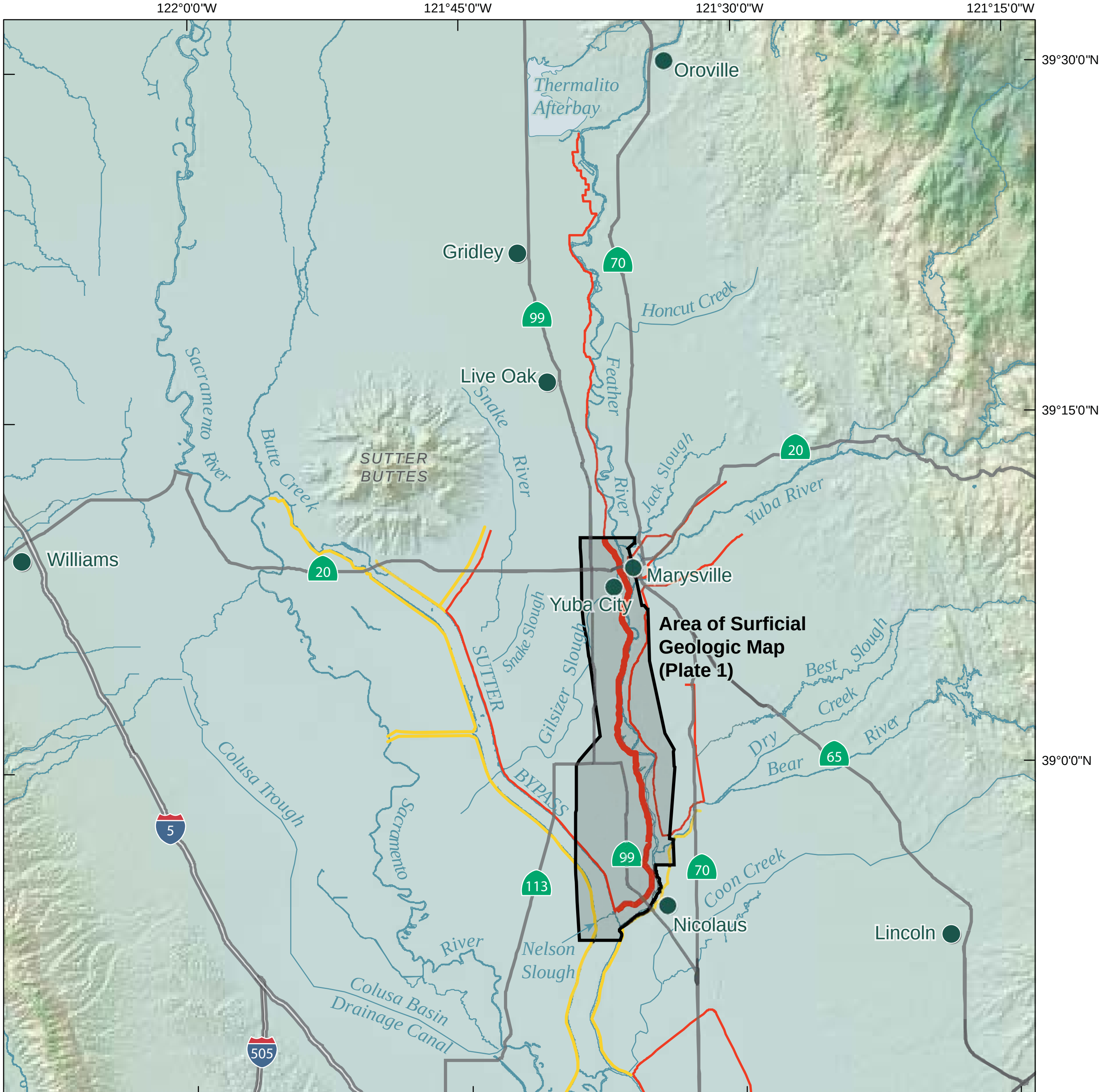
USGS, Nicolaus topographic quadrangle, published 1952, remapped 1992; map scale 1:24,000, five foot contour interval.

USGS, Olivehurst topographic quadrangle, published 1952, photo revised 1973; map scale 1:24,000, five foot contour interval.

USGS, Sutter topographic quadrangle, published 1952, photo revised 1973; map scale 1:24,000, five foot contour interval.

USGS, Sutter Causeway topographic quadrangle published 1952, photo revised 1973; map scale 1:24,000, five foot contour interval.

USGS, Yuba City topographic quadrangle, published 1952, photo revised 1973; map scale 1:24,000, five foot contour interval.



Sources: NAIP, 2006

Projection: UTM Zone 10, NAD83

Explanation

Southern Feather River project levee

Urban project levee

Other levee

N

0 5 10 mi

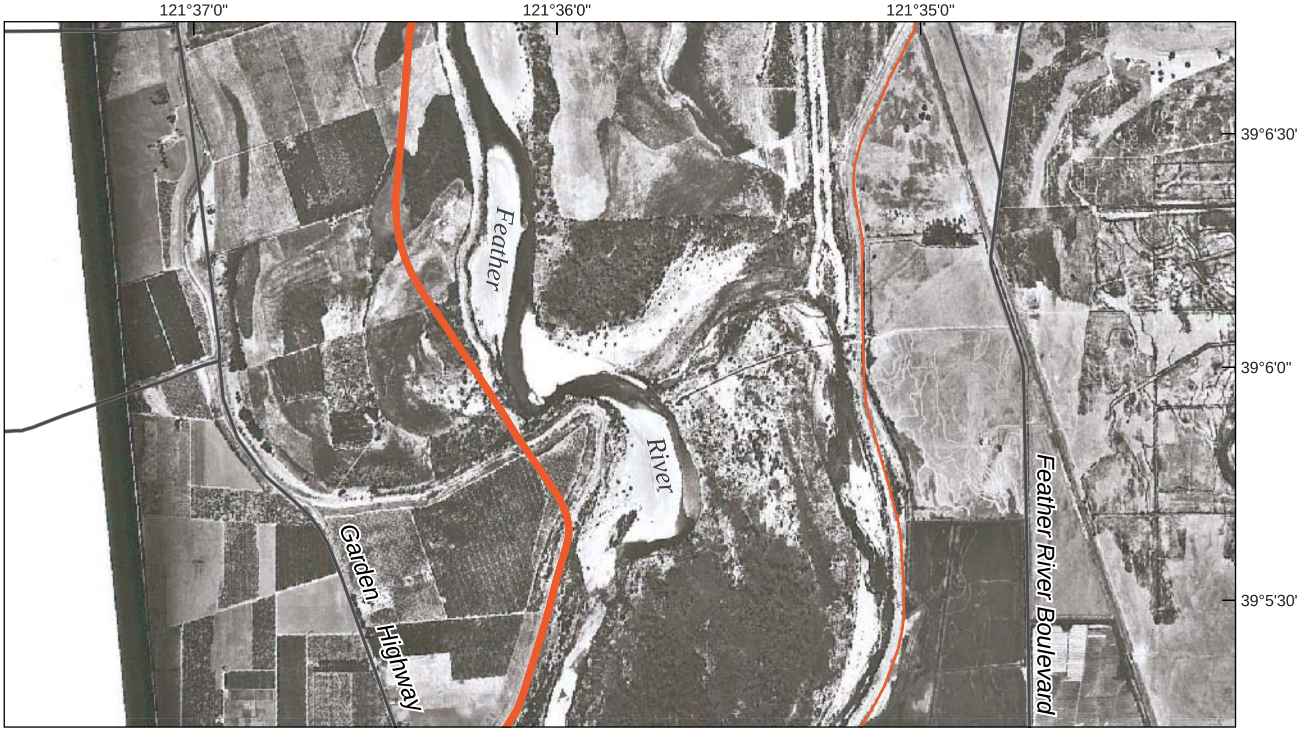
0 5 10 km

WLA

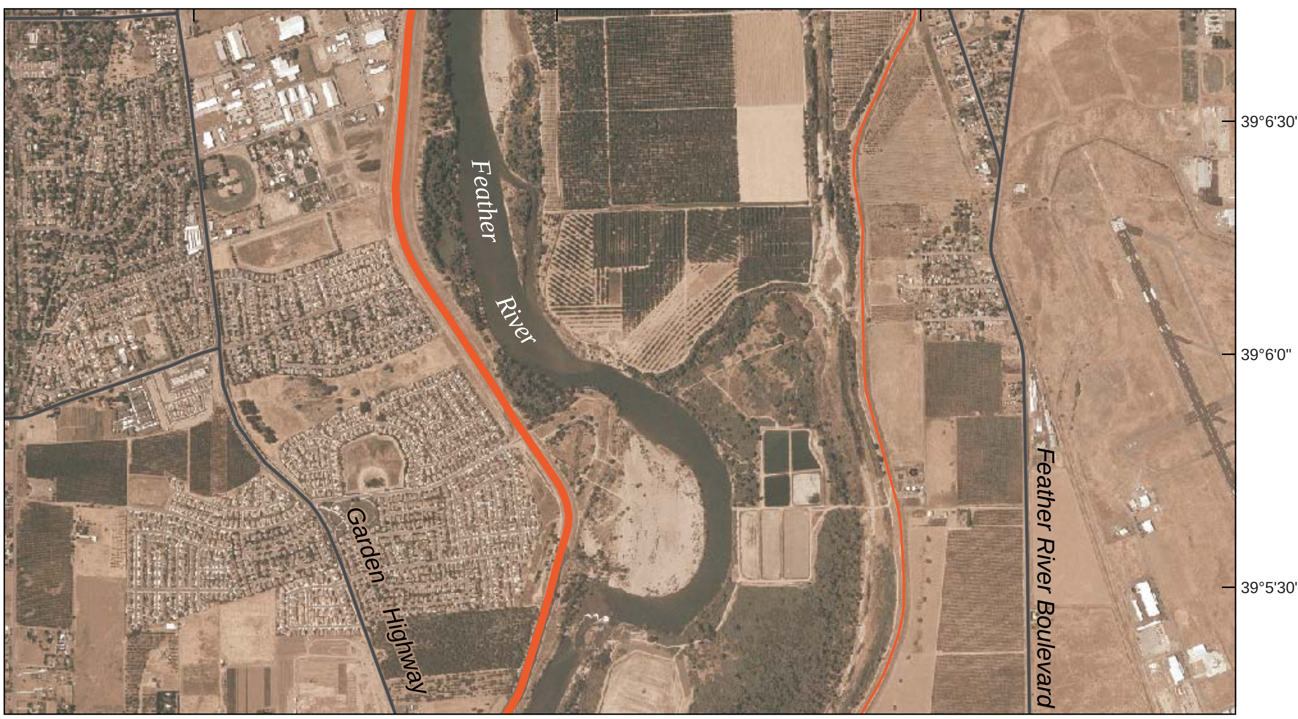
Map of Central Valley near Sutter Buttes, California

DWR URBAN LEVEE PROJECT

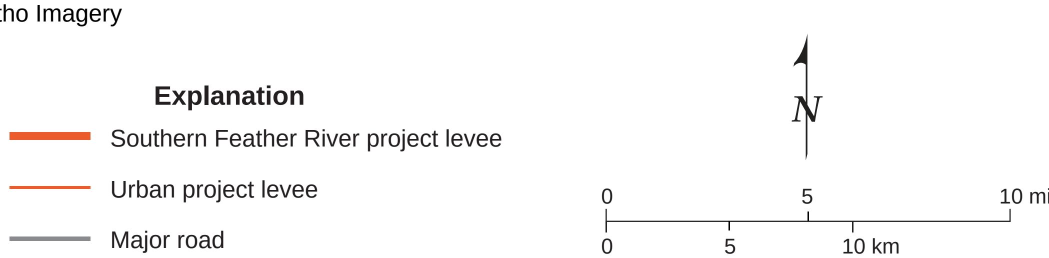
Figure 1



A. 1937 USDA Air Photo



B. 2006 NAIP Ortho Imagery

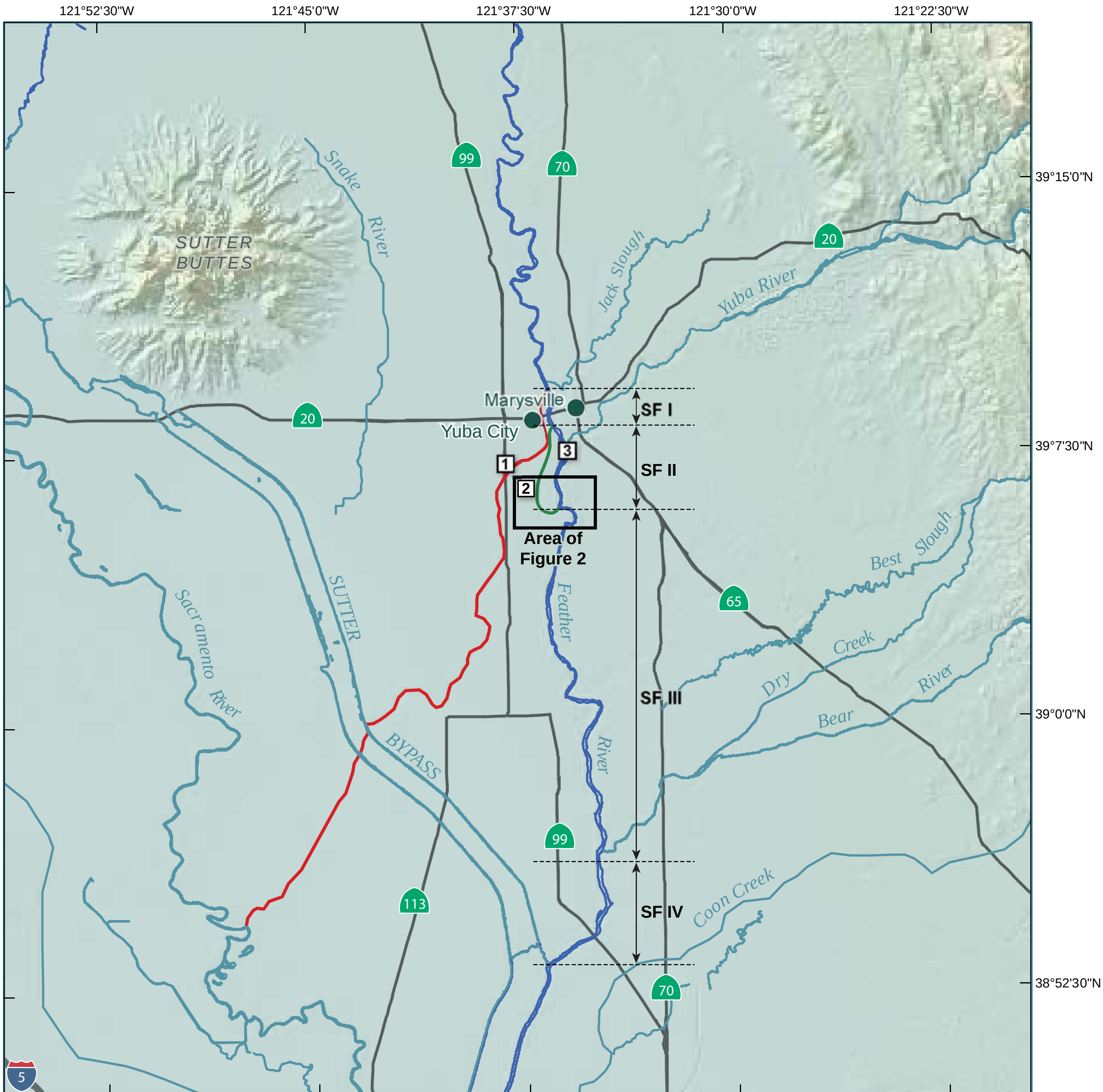


WLA

Aerial Imagery of the Feather River at Shanghai Bend

DWR URBAN LEVEE PROJECT

Figure 2



Source: ESRI, 2006

Projection: UTM Zone 10, NAD83

Explanation

- 3 Modern Feather River Channel
- 2 Abandoned arm of the Feather River
- 1 Ancestral Feather River Channel (Gilsizer Slough)
- **SF I** Reach of Southern Feather River Study Area

N

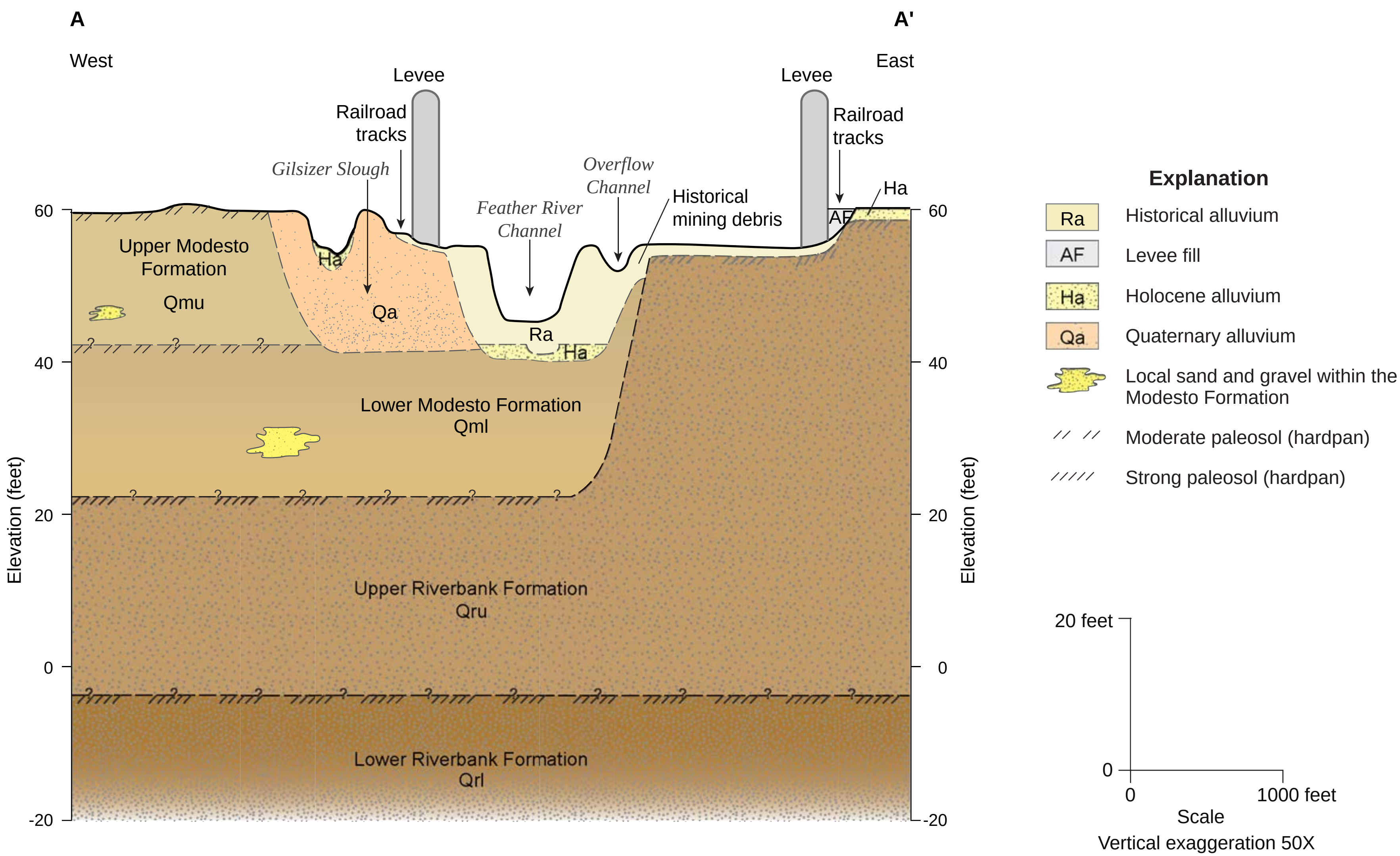
0 5 mi

0 5 km

WLA **Map Showing the Eastern Migration of the Feather River**

DWR URBAN LEVEE PROJECT

Figure 3



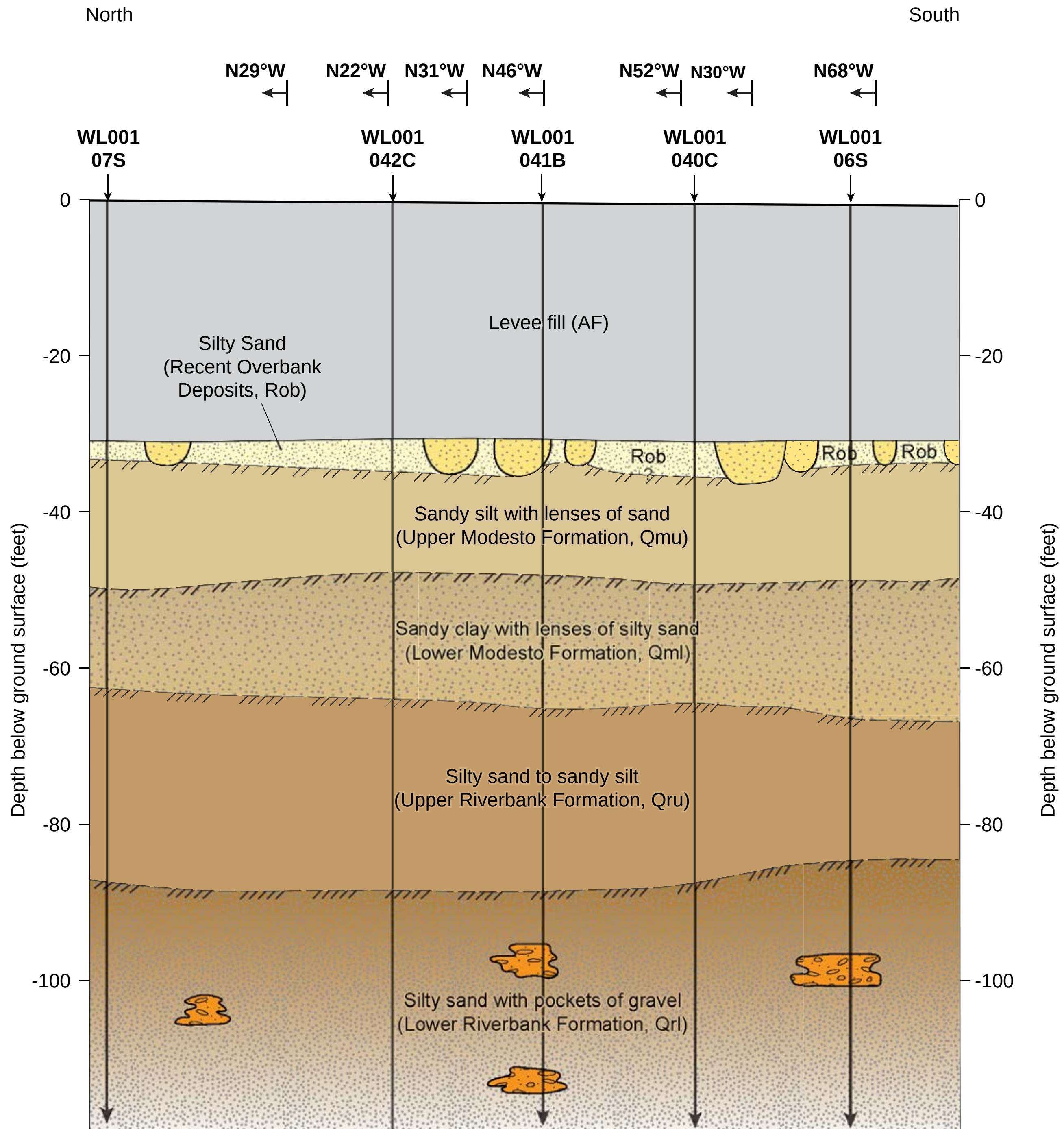
WLA **Conceptual Subsurface Diagram across the Feather River at Yuba City**

DWR URBAN LEVEE PROJECT

Figure 4

1881 South Feather River

Modified 09.03.09



Explanation

Recent crevasse splay, surficial geologic map unit Rcs

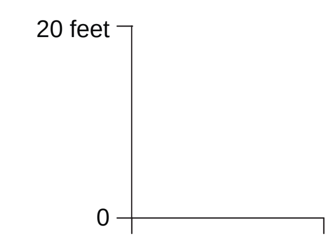
Local sand and gravel within the Riverbank Formation

Moderate paleosol (hardpan)

Strong paleosol (hardpan)

N46°W Bend in Section

Notes: 1. See Plate 1 for location of cross section.
2. Surficial geologic units and contacts from this study and Helley and Harwood (1985).
3. Bottom of hole (BOH) values shown as total depth below ground surface.
4. Borehole names and horizontal distance shown above from draft URS logs and location maps. Geologic relations could change if borehole locations revised
5. Drilling method indicated as last letter in borehole names:
S = Sonic Vibracore;
C = Cone Penetrometer Test;
B = Mud Rotary with SPT



Scale

Vertical exaggeration 50X


Plate 1 - Surficial Geologic Map of the Feather River, Southern Section
This map shows surficial geologic deposits and levees as they existed in 1937. Map units and boundaries are drawn by interpretation of historical aerial photography supplemented by data from historical maps and surveys. For reference, the mapping is superimposed on modern U.S. Geological Survey topographic base map prepared in 1952 and photo revised in 1973. See accompanying report for complete descriptions of map units, process descriptions and methodology.
Explanation
Geologic contact; dashed where approximate, dotted where concealed, queried where uncertain; solid contacts within 30' of line shown on map.
SF-II
Geomorphic Reaches Discussed in Text
Project Levees
Cross Section
A
A'
WSL001_006S
Borehole locations from URS, Corp; locations from Sutter P2 Boring Locations, Region 1 Northern Area map.
W 1937
Water bodies, circa 1937.
BP
Borrow pits present in 1937.
Geologic Units
HISTORICAL
L Levees (artificial fill), circa 1937.
SP Spoils pile (artificial fill), circa 1937.
Rob Overbank deposits; sand, silt, and clay; deposited during high-stage water flow, overtopping channel banks.
Rcs Crevasse splay deposits; fine to coarse sand, with minor lenses of clay deposited from breaching of natural or artifical levees.
Rdf Distributary fan deposits; sand, silt and clay.
Rch Channel deposits; well sorted sands and fine gravels.
Rms Channel meander scroll deposits; sand, silt and clay from lateral channel migration.
Rb Channel bar deposits; fine gravel, sand, and silt deposited in or along channel lateral margins.
Rcu Cut off channel (chute); occurs on insides of meander bends within the river channel; on flood plain – entrenchment of overflow channels into hydraulic mining debris.
Rdc Distributary channel deposits, trace gravel, sand, silt, and clay; channelized flow conducting sediment to floodplain.
Rofc Overflow channels; vertically stratified sand, silt, and clay in floodplain channels occupied primarily when high-stage water overtops channel banks.
Rsl Slough deposits; sand, silt and clay, fining upward facies, low-energy channel deposit.
Ra Alluvial deposits, undifferentiated; sand, silt, and minor lenses of fine gravel.
HOLOCENE
Hob Overbank deposits; sand, silt, and clay; deposited during high-stage water flow, overtopping channel banks.
Hcs Crevasse splay deposits; fine to coarse sand, with minor lenses of fine gravel deposited from breaching of natural or artifical levees.
Hdf Distributary fan deposits; sand, silt and clay.
Hofc Overflow channels; vertically stratified sand, silt, and clay in channels occupied when high-stage water overtops channel banks.
Hch Channel deposits; sorted sands and silts; fining upward.
Hb Channel bar deposits; fine sand, and silt deposited in or along channel lateral margins.
Hdc Distributary channel deposits, sand, silt, and clay.
Hsl Slough deposits; sand, silt and clay, fining upward facies, low-energy channel deposit.
Ha Alluvial deposits; undifferentiated; sand, silt, and minor lenses of gravel; under cultivation in 1937.
Qn Basin deposits; fine sand, silt and clay, dark yellow to dark yellowish brown, under cultivation in 1937.
Qs Marsh deposits; silt and clay, likely organic-rich; perennially or seasonally submerged on 1937 photography.
PLEISTOCENE
Qmu Modesto Formation; upper member; unconsolidated gravel, sand, silt, and clay.
Qml Modesto Formation; lower member; unconsolidated to semi-consolidated gravel, sand, silt and clay.
Qru Riverbank Formation; upper member, semi-consolidated to consolidated gravel, sand, silt and minor clay.
Qrl Riverbank Formation; lower member; consolidated gravel, sand, silt, and clay, generally associated with strong duripan horizon.
Stratigraphic Correlation Chart
Time
Depositional Environment
Epoch
Channel deposits
Floodplain and alluvial-fan deposits
Flood basin deposits
Cultural deposits
Historical
Rch Rdc Rb Rsl Rms Rofc Rcu
Qa Ra Rcs Rdf Rob
Qs Qn
L SP
Holocene
Hch Hdc Hb Hsl
Ha Hdf Hcs Hob Hofc
Latest Pleistocene
Qmu
Qml
Pleistocene
Qru
Qrl
SF-I
SF-II
SF-III
SF-IV
1:20,000
N
0 0.5 1 Miles
0 0.5 1 Kilometers
Map projection: UTM NAD83 Zone 10N
Topographic base USGS quadrangles:
USGS, Gilsizer Slough topographic quadrangle, published 1952, photo revised 1973; map scale 1:24,000, five foot contour interval.
USGS, Nicolaus topographic quadrangle, published 1952, remapped 1992; map scale 1:24,000, five foot contour interval.
USGS, Olivehurst topographic quadrangle, published 1952, photo revised 1973; map scale 1:24,000, five foot contour interval.
USGS, Sutter topographic quadrangle, published 1952, photo revised 1973; map scale 1:24,000, five foot contour interval.
USGS, Sutter Causeway topographic quadrangle published 1952, photo revised 1973; map scale 1:24,000, five foot contour interval.
USGS, Yuba City topographic quadrangle, published 1952, photo revised 1973; map scale 1:24,000, five foot contour interval.
Plate 1 - Surficial Geologic Map of the Feather River, Southern Section
WLA
WILLIAM LETTIS & ASSOCIATES, INC.
Walnut Creek, CA
1881_URS_Feather_South.mxd
09/04/2009
Geologic Mapping by J. Pearce and A. Streig
Digital Cartography by M. Ticci

WLA

WILLIAM LETTIS & ASSOCIATES, INC.

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September 8, 2009

Mr. Juan Vargas
URS Corporation
2870 Gateway Oaks Drive, Suite 150
Sacramento, CA 95833

RE: Surficial geologic mapping and geomorphic assessment, California Department of Water Resources Urban Levees Project, Sutter Bypass, Sutter County, California

Dear Mr. Vargas:

This memorandum presents the surficial geologic mapping and preliminary geomorphic assessment of the eastern Sutter Bypass area, for the California Department of Water Resources (DWR) Urban Levees Project geotechnical characterization. The goal of this mapping and geomorphic assessment is to provide information on the type and distribution of surface and shallow subsurface deposits that likely underlie the project levees along the eastern part of the bypass. The purpose of this study is to develop spatially-continuous geologic data and a conceptual model that allows reasonable stratigraphic interpretations between widely-spaced subsurface explorations, with respect to potential levee underseepage (i.e., Llopis et al., 2007). This letter presents the technical approach, surficial geologic map, conceptual geomorphic model, and initial results based on map analysis and preliminary review of available Phase 1 geotechnical data.

We appreciate the opportunity to provide these geomorphic and geologic data and preliminary interpretations of the shallow stratigraphic conditions in the Sutter Bypass study area. Please do not hesitate to call either of the undersigned if there are any questions or comments.

Respectfully,

WILLIAM LETTIS & ASSOCIATES, INC.

Justin Pearce, C.E.G. 2421
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1.0 Approach

The approach to developing a surficial geologic map of the Sutter Bypass area (Figure 1, Plate 1) consisted of analysis of the following data: Aerial photography (black and white stereo-pairs taken in 1937, ~1:20,000-scale); early USGS topographic maps (i.e., 1911); published surficial geologic maps (Helley and Harwood, 1985); early and modern soil survey maps (Strahorn et al., 1911; Lytle, et al., 1988); field reconnaissance visit on June 22, 2007; and other maps and documents. Synthesis of these data allow for the development of a detailed surficial geologic map that provides an initial understanding of primary geomorphic processes that have acted in the study area during recent and historical geologic time. Through this mapping, we identify primary geomorphic features and associated surficial geologic deposits, such as abandoned paleochannels, marsh and basin deposits, flood-basin deposits, and other features commonly associated with flood-basins adjacent to large, active river systems. Knowledge of fluvial processes and the ability to recognize depositional environments in the geologic record are key to identifying locations along levees where underseepage is most likely to occur (Llopis, 2007).

The surficial geologic map was developed at the nominal scale of the aerial photography (1:20,000). This scale establishes the resolution of the map (Plate 1). The map unit contacts shown on the surficial geologic map should be considered approximate, and accurate to no more than about 30 feet on either side of the line shown on the map. The 1937 aerial photographs are the primary data set for interpreting the surficial geologic deposits because: (1) they are the oldest high-quality images that pre-date much of the urbanization and landscape alteration within present-day Sutter County (Figure 2); and, (2) these data represent a close approximation to the surficial deposits that were likely present at the ground surface prior to the construction of the levees. The 1937 photographs generally were taken in late summer or early autumn (i.e., August). By 1937, the area had experienced moderate cultivation that locally obscures geomorphic conditions. However, integration of data from the 1937 photography, old and recent topographic maps, geologic maps, soil surveys and historical documents provides sufficient information to delineate many of the pre-historic and historic surficial deposits in detail. Taken together, these data provide key insights to the geomorphic processes and resulting deposits that may affect levee underseepage.

Additional flood-basin or floodplain deposition may have occurred after 1937, due to flood overflows, levee overtopping, or localized levee failure. A time series analysis that interprets successive aerial photographs taken after major flood events (i.e., 1955) or known local levee failures (i.e., 1986) may reveal additional information on surficial deposits in the Sutter Bypass area. Such analyses are beyond the scope of this study. The data and interpretations presented herein address the primary goal of characterizing the type and distribution of deposits likely present directly beneath the project levees.

1.1 Report Preparation Quality Control

The surficial geologic map data and geomorphic interpretations presented in this memorandum were subject to quality control and quality assurance procedures as required by the Levee

Geotechnical Evaluation Project Management Plan (PMP). The surficial geologic map data developed by this study were reviewed for accuracy and completeness through an internal review and an independent technical review by Dr. Janet Sowers of WLA. Results of QA/QC review were documented using PMP Exhibit 2.2-3 (Independent Technical Review Report) and are kept on file according filing control plan. Subsurface data shown on diagrams were provided as draft information, and were not verified for accuracy or completeness by this study.

2.0 Geologic Setting

The Sutter Bypass (Bypass) study area lies southeast of the volcanic Sutter Buttes, between the Sacramento and Feather Rivers. The project levee addressed in this study borders the eastern side of the Sutter Bypass, extending from the Wadsworth Canal southeast to the Feather River (Figure 1). The Bypass levee generally trends northwest-southeast, and ties in to the Feather River west bank levee.

The Bypass levee lies northeast of Sutter Basin, a low-lying area east of the Sacramento River and west of the Feather River, where overflow and floodwaters from Butte Basin (located northwest of the Sutter Buttes), the Sacramento River, and the Feather River produced a seasonally marshy area. Except for the Sutter Buttes area, the regional land surface is nearly flat, and along the Bypass area gently slopes southwest at an elevation of about 30 to 40 feet. Construction of the Sutter Bypass was completed in 1924 to serve as an overflow for Sacramento River floods in the winter, and a source of irrigation in the summer (DWR, 1976). The eastern levee was enlarged in 1942 (Corps of Engineers, 1953). Prior to cultural modification, surface water runoff in the Bypass area was delivered to the Sutter Basin via intermittent, meandering creeks and sloughs from the northern Central Valley, including: Snake River, Snake Slough, Gilsizer Slough, Nelson Slough, and flood overflow channels emanating from the western side of the Feather River. The construction of the Bypass levee blocks water from the east that normally drains to the Sutter Basin and Sacramento River (DWR, 1976). Presently, many of the natural drainages and channels have been replaced by linear ditches, agricultural drains, and canals (Figure 2).

3.0 Surficial Geologic Mapping

Published surficial geologic maps of the Sutter Bypass study area generalized the surficial deposits primarily as late Quaternary basin (map unit Qb) deposits, with localized units of late Quaternary alluvium, Quaternary Modesto Formation (lower member), and Quaternary Riverbank Formation (lower member) (Helley and Harwood, 1985). These map units were delineated at a regional scale (i.e., 1:62,500). The current analysis of the Bypass uses this geologic framework as a basis for more detailed mapping of late Holocene alluvium and geomorphic features (Plate 1). The surficial geologic map units within the Sutter Bypass study area are described below, in order from oldest to youngest.

The oldest map unit exposed in the study area is the late Quaternary Riverbank Formation (lower member), and is mapped in the south portion of the study area east of Nelson Slough, where it likely directly underlies the project levee near the latitude of Laurel Avenue (Plate 1). This formation (map unit Qrl) is present in the shallow subsurface beneath much of the bypass area, and consists of alluvial-fan deposits derived from the Sierra Nevada during the middle Pleistocene (about 400,000 to 200,000 years ago). The Riverbank Formation is semi-consolidated, and is associated with the presence of a well-developed hardpan (or, duripan) layer that is a product of soil-forming processes over substantial geologic time. This hardpan layer reflects an ancient land surface that locally is buried by younger deposits. Soils developed on the Riverbank Formation in the Bypass area include the San Joaquin loam of Strahorn et al. (1911) and the Yuvas loam (Lytle et al., 1988), both of which document a strongly cemented hardpan at depths of about 1.5 to 3 feet below ground surface.

The late Pleistocene Modesto Formation is younger than the Riverbank Formation and is present in the map area primarily along the margin of Gilsizer Slough and directly east of Highway 113 (Plate 1). This unit is divided into two members, a lower (older) unit that is about about 42,000 to 29,000 years old (Qml), and an upper member that is about 24,000 to 12,000 years old (Qmu) (Helley and Harwood, 1985). The Modesto Formation, in general, consists of unconsolidated sand, silt, and clay, and is associated with a moderate amount of secondary (pedogenic) clay accumulation. This clay-rich horizon may form laterally continuous zones of low hydraulic conductivity. These soil horizons may extend across boundaries between coarse and fine-grained strata within the latest Pleistocene alluvium, and may form relatively continuous zones of low vertical hydraulic conductivity within the Modesto Formation. Soils developed on the Modesto Formation include the Gridley loam of Strahorn et al. (1911) and the Marcum clay loam with “siltstone” hardpan (Lytle, 1988).

Younger surficial deposits overlying the Riverbank and Modesto Formation include late Quaternary marsh, basin, and alluvial deposits (map units Qs, Qn, and Qa, respectively), which are considered Holocene age (i.e., less than 11,000 years old). The widespread basin deposits are about 4 to 8 feet thick and bury the gently southwest dipping Modesto Formation (Figure 3). The thickness of the basin deposits increases to the southwest, in the direction of Sutter Basin (Figure 3). The soils developed on the basin deposits generally are associated with the Stockton clay adobe and Marcuse clay of Strahorn et al. (1911) and the Oswald clay (Lytle et al., 1988), and thus represent immature soils with overall fine-grained textures. Undifferentiated alluvial deposits (map Qa, Plate 1) are present along Gilsizer Slough, and are inset (i.e., topographically lower) into the adjacent Modesto Formation. The Quaternary marsh deposits (map unit Qs, Plate 1) are present between the Sutter Bypass levees northwest of Gilsizer Slough, and are also fine-grained deposits that are differentiated from basin deposits by usually being underwater or having standing water at the time when the 1937 photographs were taken (usually late summer to early autumn).

Inset into the units described above are deposits of Holocene alluvial channels (map unit Hch, Plate 1), which are a network of moderately sinuous channels with southwesterly orientations. These channels appear to be mostly filled with sediment by the time of 1937 photographs, and are expressed only locally as subtle topographic lows in the ground surface. Many of these channels extend west of, and therefore cross beneath, the eastern Sutter Bypass levee (Plate 1). The alluvial channels west of Gilsizer Slough start on the alluvial plain as intermittent creeks, and are not directly connected to the Feather River (USGS Tisdale Weir quadrangle, 1911).

The channel deposits are tentatively associated with the Liveoak series, sandy clay loam soil (Lytle et al., 1988), and consist of a lower, sandy unit that fines-upward into an upper, silt and clay layer.

Subdivisions of the Holocene channels include sloughs (map unit Hsl, Plate 1), distributary channels (map unit Hdc), and overflow channels (map unit Hofc). These deposits, in general, also consist of a fining-upward sequence of sand, silt, and clay. The sloughs are present primarily east of Highway 113 (Plate 1) and have southwesterly orientations. The sloughs are ephemeral channels that drain the alluvial plain between Gilsizer Slough and the Feather River. The term “slough” in this study does not mean tidally-influenced channels, but instead channels that likely conveyed relatively slow-moving water from direct precipitation and sheet-flow runoff. The overflow channels convey flood flows that overtop the banks of the Feather River onto the floodplain, and are interpreted as higher-energy channel systems relative to the sloughs. The distributary channels route flow from and sediment onto the floodplain, and end at distributary-fan deposits. The overflow and distributary channel deposits are present in the southeastern portion of the Bypass area, south of the latitude of Laurel Avenue (Plate 1).

Localized deposits related to the Holocene alluvial channels are bars (map unit Hb) that typically occur in the medial and lateral portions of the channels, and distributary fan deposits (map unit Hdf) that occur where the channel becomes unconfined and has deposited sediment on the basin floor. Channel bars are relatively uncommon in the Sutter Bypass study area. Distributary fans are common in the southeast portion of the Bypass area, south of the latitude of Sacramento Avenue (Plate 1). The distributary-fan deposits likely consist of unconsolidated fine sand and silt (i.e., Strahorn et al., 1911).

Historical geologic deposits are present along the length of the Bypass study area (i.e., map unit Rch, map unit Rdf). The term “historical” is applied to deposits that are estimated to be less than 150 years old. These deposits share the same genetic origin as the Holocene deposits described above. The historical channel deposits are differentiated from the Holocene channel deposits on the basis of cross-cutting relationships with other map units, relative degree of geomorphic expression and/or dissection, and correlation with land surface expression on the early and modern topographic maps. The Bypass eastern levee overlies the former locations of Holocene and historical alluvial channels in several locations throughout its length (Plate 1).

Undifferentiated Holocene and historical alluvium (map units Ha and Ra) is mapped in the southeastern Bypass area, near the confluence of the Sutter Bypass and the Feather River, generally east of Sawtelle Road (Plate 1). The undifferentiated map unit is delineated where the morphology of these deposits is indistinguishable on 1937 photographs as a result of cultural modifications (i.e., agriculture). The soils developed on the undifferentiated historical alluvium generally correspond with the Sacramento series fine sandy loam and silt loam of Strahorn et al. (1911) and the Shanghai silt loam (Lytle et al., 1988). There is no hardpan layer associated with these soils, supporting the interpretation of geologically young deposits.

4.0 Conceptual Geomorphic Model

Based on synthesis of surficial geologic mapping, topographic maps, soil surveys, geologic maps, and review of readily available subsurface geotechnical information, we present a preliminary conceptual geomorphic model describing general relationships among surface and subsurface deposits along the Sutter Bypass study area. This conceptual model provides a consistent basis for understanding the type and distribution of surficial geologic deposits, primary geomorphic processes, and shallow subsurface stratigraphy in the area. Identification of subsurface stratigraphic formations is challenging, primarily because of a lack of distinctive and laterally extensive stratigraphic marker beds within late Quaternary deposits of the northern Central Valley (i.e., Page, 1986), and because there is little apparent difference in lithology between the late Quaternary formations (i.e., Helley and Harwood, 1985). This study relies heavily on the identification and local correlation of hardpan horizons and deposit color and density changes to delineate subsurface formations.

In a general sense, the Sutter Bypass levees traverse across the distal portions of ancient alluvial-fan deposits that were derived from the Sierra Nevada, and prograded westward onto the valley floor (i.e., Riverbank and Modesto Formations). These Pleistocene deposits are exposed at the ground surface northeast of the Bypass study area (Helley and Harwood, 1985; Page, 1986), dip to the southwest and are mantled by younger fine-grained basin deposits (Figure 3). In contrast, the Modesto Formation is exposed at the ground surface along Gilsizer Slough and directly east of Highway 113 (Plate 1). The surficial map pattern of the Modesto deposits in these locations suggests depositional lobes from an ancestral Gilsizer Slough. These deposits may have been related to discharges and sediment loads that were higher than present-day conditions. These deposits may, perhaps, represent an ancestral Feather River channel location that occupied the present-day Gilsizer Slough during the latest Pleistocene and was subsequently abandoned.

The surficial geologic mapping (Plate 1) shows differences in deposit type and distribution from northwest to southeast along the Bypass, which are associated with changes in watershed production of water and sediment, related geomorphic processes, soil profile development, and the underlying subsurface hardpan layer. These differences illustrate the diversity of past geomorphic processes along and near the Bypass and, as a consequence, the type of geologic deposits at and near the ground surface. The surficial geologic map allows the interpretation of “reaches” along the Bypass within which geomorphic processes and their associated deposits are likely to be relatively consistent. The Bypass study area consists of four general reaches, from northwest to southeast, each having characteristic deposit types and distributions (Plate 1).

The westernmost reach of the Bypass study area extends from the junction with the Wadsworth Canal to directly south of the Tisdale Weir (“Reach I”, Plate 1). The levee along this reach, about 8.1 miles long, primarily overlies fine grained basin deposits accumulated on the valley floor over geologic time. This deposition resulted from flooding of the Sacramento and Feather Rivers, tributaries draining Sutter Buttes, and sheet flow from the generally flat valley floor. Holocene and historical channel deposits (map units Hch and Rch, Plate 1) are inset into the basin deposits. These southwest-trending alluvial channel deposits locally underlie the Bypass levee, and result in local differences in material textures beneath the levee (Figure 4). About 27 abandoned channels traverse the levee along this reach (approximately 3 channels per levee mile). The channels are about 250 feet wide, but range from about 100 to 300 feet wide (Plate 1). In this area, the channels are about 6 to 8 feet deep, and are typically filled with sand, silt, and clay in a fining-upward sequence, i.e., coarser-grained sand overlain by about one to two feet of silt and clay. This sedimentary sequence may be conducive to seepage where relatively more-permeable channel sands are overlain by a relatively thin, fine-grained "blanket" layer.

The second reach along the Bypass, about 1.1 miles long, extends across Gilsizer Slough ("Reach II", Plate 1), where Modesto Formation deposits are present at the ground surface. Undifferentiated alluvium (map unit Qa, Plate 1) is present along the historically-active Gilsizer channel floor, and is inset to the Modesto Formation (Figure 5). The Gilsizer Slough alluvium extends beneath the eastern and western Bypass levee, and thus represents the progradation of younger deposits with respect to the Modesto Formation. Along this reach, the Bypass levee is underlain by younger Gilsizer Slough alluvium flanked by the relatively denser, semi-consolidated late Pleistocene Modesto deposits (Figure 5). Areas where the levee directly overlies the Modesto Formation may be relatively less conducive to underseepage, as the associated hardpan layer may form locally continuous zones of low hydraulic conductivity.

The third reach along the Bypass extends from the Gilsizer Slough to the latitude directly south of Laurel Avenue, and is about 6.6 miles long ("Reach III", Plate 1). This reach is generally similar to Reach I, except Reach III has Pleistocene deposits (i.e., lower Modesto and Riverbank Formations) exposed at or very near the ground surface, and has a sparser channel density (about 2 channels per levee mile) compared to Reach I. About 14 southerly-oriented sloughs are mapped across this reach and locally underlie the Bypass levee (Plate 1). The sloughs originate from the Feather River, near Star Bend and Shanghai Bend, extending southward toward the Bypass. The sloughs along Reach III are about 250 feet wide, but range from about 100 to 300 feet wide, similar to Reach I (Plate 1). In this area, the channels are also probably about 6 to 8 feet deep, and probably filled with sand fining-upward to silt and clay. These channel deposits may be conducive to underseepage because of the deposit stratigraphy that has coarser-grained sand overlain by about one to two feet of silt and clay. Late Quaternary Riverbank Formation is at the ground surface along the southwestern end of Reach III (Plate 1), and likely is not conducive to seepage due to the dense and strongly-developed hardpan clay layer that is usually at about 1.5 to 4 feet depth below ground surface.

The fourth reach along the Bypass extends from directly south of the latitude of Laurel Avenue to the confluence with the Feather River west bank levee ("Reach IV", Plate 1). Reach IV, about 1.9 miles long, has Holocene and historical alluvium at the ground surface along this reach of the Bypass, primarily because of the proximity to the Feather and Bear Rivers (Plate 1). About 8 distributary channels, usually 90 feet wide but ranging from 45 to 190 feet wide, cross the floodplain in southwesterly orientations, leading to geologically young distributary-fan sediments. These sediments, primarily consisting of fine to coarse sand and silt, probably were deposited as a result of increased sediment and water input contributed to the Feather River from the Bear River; the confluence located directly upstream from this reach of the Bypass (Figure 1). Historically, the Feather River and the Bear River have aggraded from substantial mining debris input, thus reducing channel cross sectional area (i.e., James, 1999).

This reduction of cross section area, coupled with the trajectory of floodflow from the Bear River watershed, resulted in water overtopping the Feather River channel banks, and depositing sediment onto the western floodplain where the Bypass levee is located (Plate 1).

5.0 Applications to the Urban Levee Project

Based on synthesis of the surficial geologic map with preliminary Phase 1 borehole and cone penetrometer (CPT) data, the Bypass levee generally is underlain by relatively young fine-grained clay and sandy clay deposits that are laterally interrupted by local coarser channel fill deposits (i.e., Figures 3, 4, 5, and 6).

The northernmost reach of the Bypass levee ("Reach I") is predominantly underlain in the shallow subsurface by relatively young fine-grained clay and sandy clay deposits. These basin deposits are laterally interrupted by coarser-grained deposits filling abandoned channels that are about 250 wide (Plate 1, Figure 4). Mud rotary borehole WSESBP_011B, which penetrated channel unit Rch norths of Gilsizer Slough (Plate 1), indicates the channel deposit is about four-feet thick, consisting of about 60% fine to coarse sand (medium dense) with clayey sand. The clayey sand grades upward into clay, of about 45% sand fraction. This suggests locally coarse and unconsolidated, and therefore likely permeable, material in the channel fill. Based on review of adjacent borehole data, the basin deposits (Figure 4) generally consist of stiff clay, with less than 10% fine sand. It is likely that most or all of the small channels mapped herein as unit Rch are similar in textural characteristics and depths, because of similar genetic origin and geomorphic process of channel development and infilling. These deposits underlie Reach I in at least 27 places between Wadsworth Canal and Gilsizer Slough (Plate 1).

Reach II crosses late Pleistocene and Holocene geologic deposits associated with Gilsizer Slough (Plate 1). Review of subsurface borehole and CPT data indicate that the basin deposits north of the slough consist of medium stiff to stiff clays (Figure 5). The channel fill deposits within Gilsizer Slough (map unit Qa, Plate 1) consist of alternating beds of sandy gravel and clay. These channel deposits are inset into the lower Modesto Formation which, in this area, consists of very stiff sandy clay interbedded with silty sand and localized dense sand. Directly south of Gilsizer Slough, the lower Modesto Formation is at the ground surface (Plate 1). Subsurface data suggest that a hardpan horizon is encountered at about 3 to 4 feet below the ground surface. The uppermost deposit above the hardpan consists of sand and silty sand, and probably is weathered and/or culturally re-worked materials of the lower Modesto Formation. Thus, north of Gilsizer Slough, potentially low-permeability basin materials blanket the Modesto, and are locally cut by channel deposits, whereas at and south of Gilsizer Slough the local channel deposits are inset directly into the dense Modesto Formation. Where the Bypass levee rests on the unconsolidated Qa deposits within Gilsizer Slough, these coarse deposits may be associated with higher probabilities of levee underseepage. In constrast, the sections of the levee underlain directly by the Modesto Formation containing consolidated (hardpan) horizons are much less likely to experience underseepage.

Reach III is similar in geomorphic nature to Reach I, except it has a lower frequency of channels as compared to Reach I (Plate 1). It is probable that the composition of these deposits generally will be consistent with those along Reach I (i.e., coarse-grained channel fill with upper fine-grained layers). These channels are more likely to promote seepage beneath the levee compared to the basin deposits. Additionally, the Pleistocene materials that likely directly underlie the project levees along this reach (Plate 1) are relatively dense and the associated hardpan layer may form a relatively continuous zone of lower hydraulic conductivity. Where the levee directly overlies Modesto formation (NW ¼, Section 20; southeast of the Sutter Causeway), there is a lower likelihood of underseepage. There is also a lower likelihood of underseepage where the levee rests on the Riverbank Formation in lower length of Reach III (SW ½, Section 34).

Along Reach IV, geologically young Holocene and historical alluvium is beneath the Bypass levee (Plate 1). This uppermost layer, about five-feet thick, is locally cross-cut by channel deposits that also consist of silt and sand (Figure 6). Quaternary basin deposits do not directly underlie the Bypass levee along this reach. Review of Phase 1 subsurface geotechnical data indicates that these alluvial deposits consist of silty sand and sandy silt textures. Based on review of Phase 1 data in other Project areas (i.e., Marysville), the uppermost alluvium generally has low densities (i.e. loose to medium dense), and consequently relatively high permeability. The surficial mapping indicates that essentially all of this reach of the levee (about1.9 miles) is underlain by loose, unconsolidated sandy alluvium, which may be susceptible to substantial underseepage. The local recent channels (map units Ra and Rdc; Plate 1) may contain coarser deposits and may be more susceptible to underseepage.

Synthesis of the surficial mapping and geotechnical data indicate that subsurface stratigraphy along the Sutter Bypass area locally may be conducive to levee underseepage. Shallow strata typically include denser and probably semi-consolidated material (i.e., Modesto Formation) that likely contains a moderately developed low-permeability hardpan horizon. The hardpan may or may not be laterally continuous, depending on post-depositional soil formation and erosional processes. Along Reach I and III, the Modesto formation is overlain by about 4 to 6 feet of medium stiff to stiff clay (i.e., basin deposits). The basin materials locally are cross-cut by relatively loose, sandy channel deposits that have a thin fine-grained upper "blanket" layer. Therefore, this shallow subsurface stratigraphy may promote levee underseepage along certain areas of the Bypass project levees that overlie geologically young, loose, sandy channel material lies between the dense Pleistocene deposits and relatively thin, low-permeability clay-rich "blanket" layer. Along Reach IV, a layer Holocene and historical alluvium from the Feather River mantles the Modesto Formation, and also may promote levee underseepage.

Lateral and vertical variability in the shallow subsurface deposits has resulted from past geomorphic processes. The conceptual subsurface stratigraphic framework suggests that stratigraphic relationships may promote localized levee underseepage, given certain hydraulic conditions. Further spatial analyses of the surficial geologic mapping and subsurface geotechnical exploration data are needed to better constrain and characterize areas that are most susceptible to underseepage in the study area.

6.0 Limitations

This geomorphic assessment and associated data interpretation have been performed in accordance with the standard of care commonly used as the state-of-practice in the geologic engineering profession. Standard of care is defined as the ordinary diligence exercised by fellow practitioners in this geographic area performing the same services under similar circumstances during the same time period.

Discussions of surface and subsurface conditions summarized in this technical memorandum are based on geologic interpretations of subsurface soil data at limited exploration locations available to this assessment through August of 2007. Variations in subsurface conditions may exist between exploration locations, and the project team may not be able to identify all adverse conditions in the levee and its foundation. This memorandum is for the use and benefit of DWR. Use by any other party is at their own discretion and risk.

7.0 References

Army Corps of Engineers, 1953, Supplement to Standard Operation and Maintenance Manual, Sacramento River Flood Control Project, Unit No. 134, East Levee of Sutter Bypass from the Sutter Buttes Southerly to its Junction with the Feather River and the East and West Levees of Wadsworth Canal and Levees of Intercepting Canals.

California Department of Water Resources (DWR), 1976, Northern District, “Sutter Bypass Study”.

Helley, E.J., and Harwood, D.S., 1985, Geologic map of the late Cenozoic deposits of the Sacramento Valley and Northern Sierran foothills, California; 1:62,500, USGS Map File MF-1790

James, A., 1999, Time and the Persistence of Alluvium: River Engineering, Fluvial Geomorphology, and Mining Sediment in California; Geomorphology, v. 31, p. 265 - 290

Llopis, J.L., Smith, E.W., and North, R.E., 2007, Geophysical Surveys for Assessing Levee Foundation Conditions, Sacramento River Levees, Sacramento, CA; US Army Corps of Engineers, Engineer Research and Development Center, Geotechnical and Structures Laboratory publication ERDC/GSL TR-07-21, 61p.

Lytle, D.J., Kurowski, R.G., Whiting, M.L., Vinson, E.N., Vonich, P.W., Hansen, R.W., 1988, Soil Survey of Sutter County, California, 1:24,000, USDA Soil Conservation Service.

Page, R.W., 1986, Geology of the Fresh Ground-Water Basin of the Central Valley, California, with Texture Maps and Sections; US Geologic Survey Professional Paper 1401-C, 54 p., 5 plates

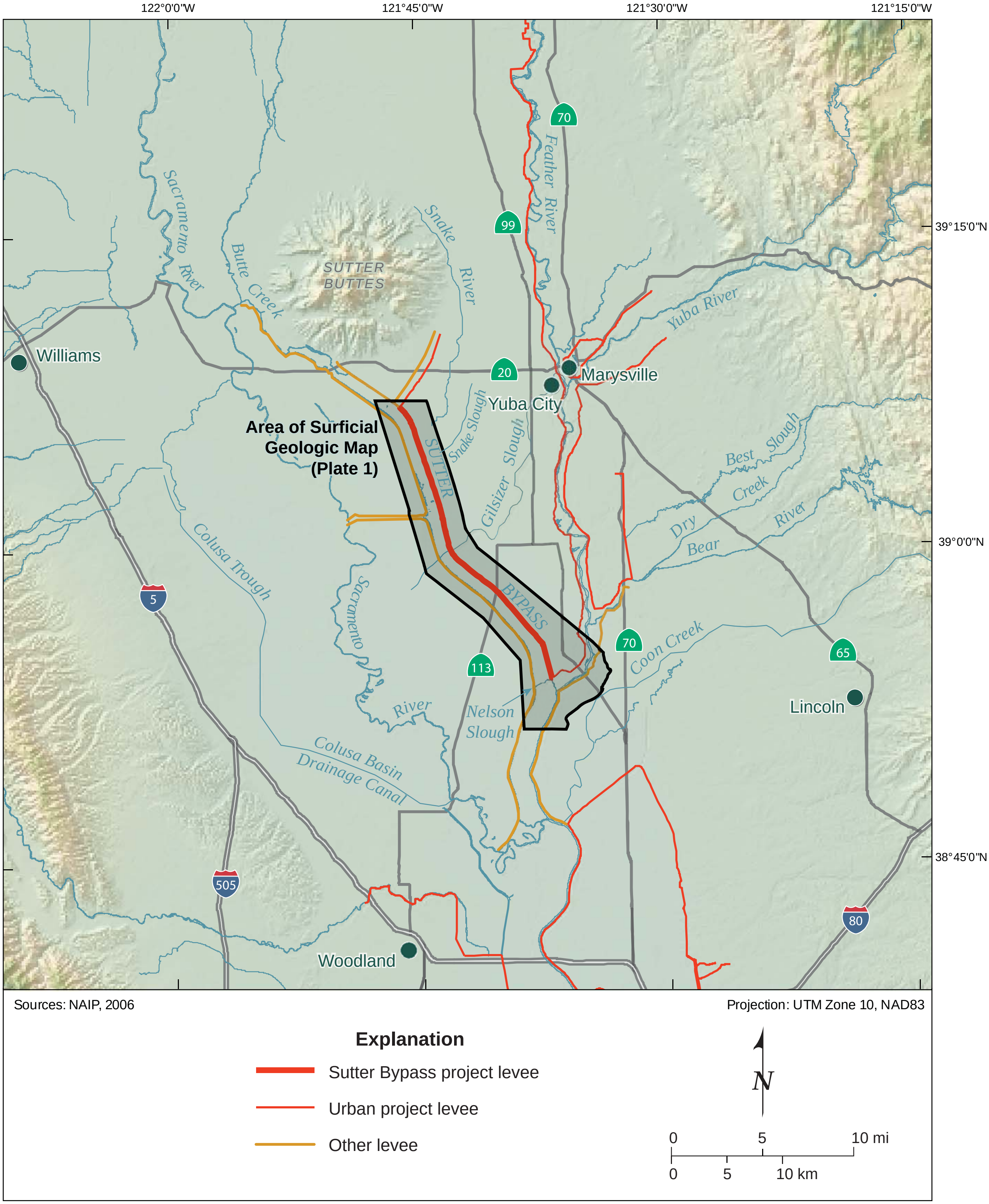
Strahorn, A.T., Mackie, W.W., Holmes, L.C., Westover, H.L., Van Duyne, C., 1911, Soil Survey of the Marysville Area, California; 1:62,500, USDA Bureau of Soils

USGS, Gilsizer Slough topographic quadrangle, surveyed 1909, published 1911; map scale 1:31,680, five foot contour interval.

USGS, Marcuse topographic quadrangle, surveyed 1909, published 1911; map scale 1:31,680, five foot contour interval.

USGS, Nicolaus topographic quadrangle, surveyed 1908, published 1910; map scale 1:31,680, five foot contour interval.

USGS, Tisdale Weir topographic quadrangle, surveyed 1909, published 1911; map scale 1:31,680, five foot contour interval.

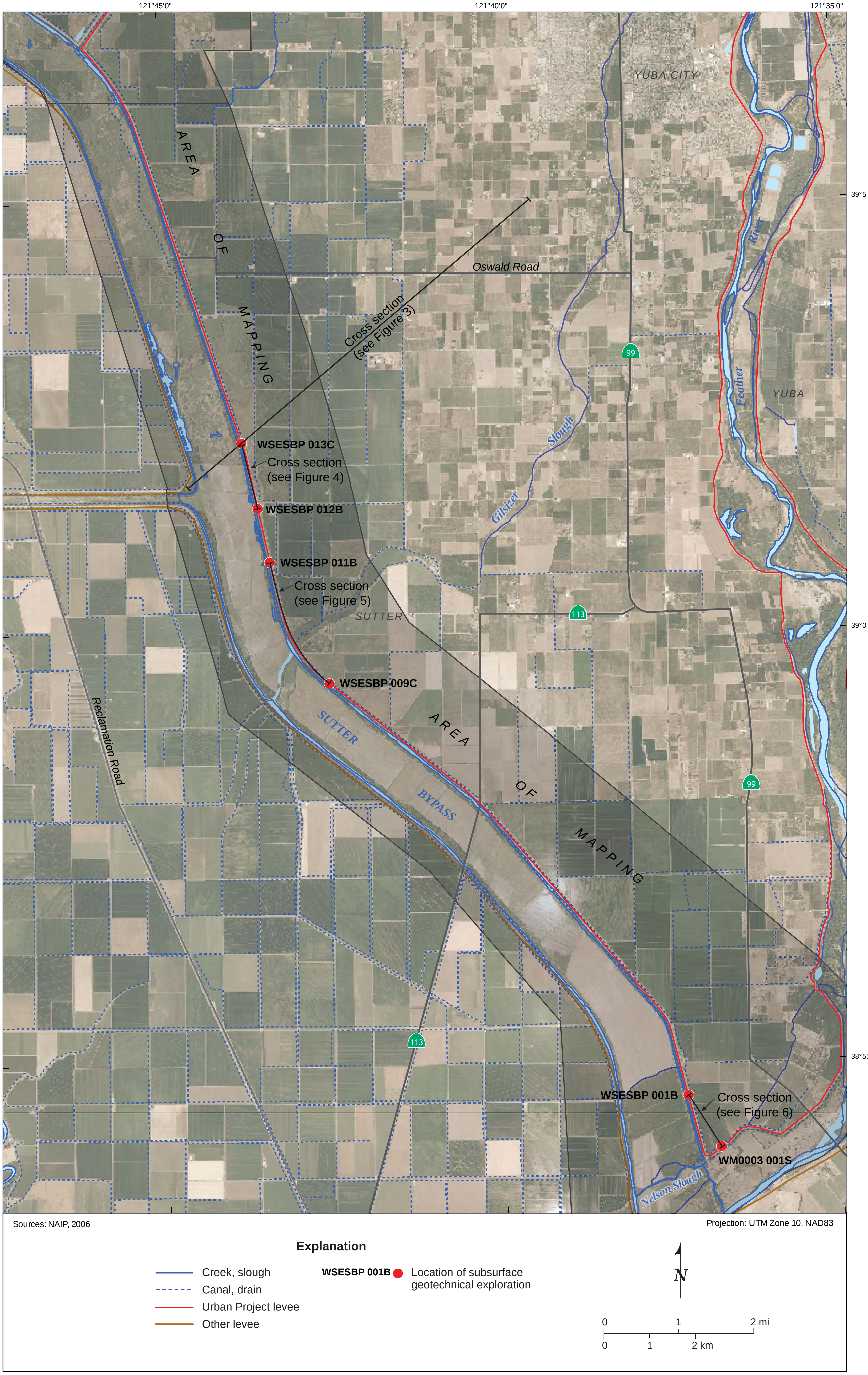


Map of Northern Central Valley, California

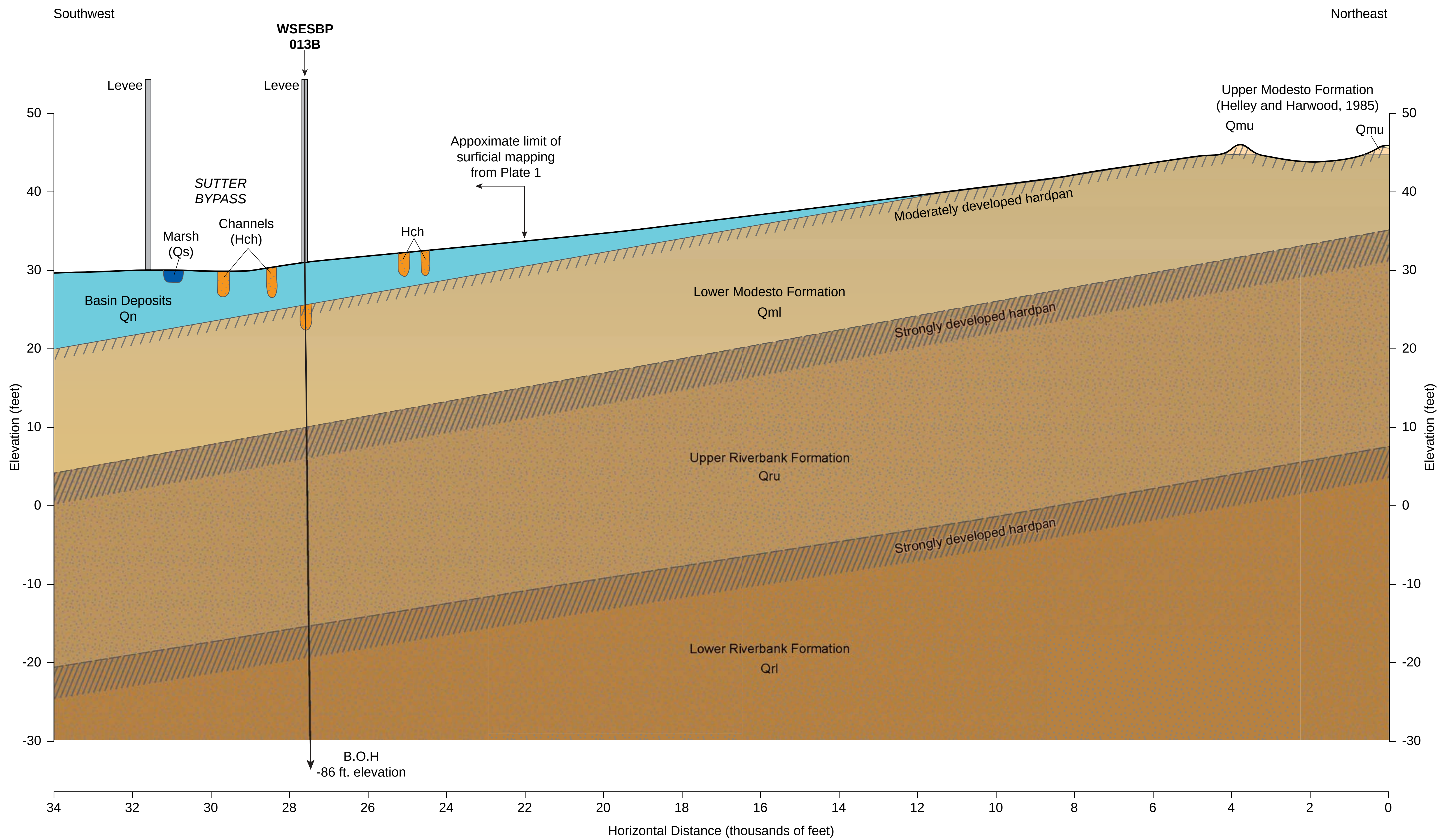
WLA

DWR URBAN LEVEE PROJECT

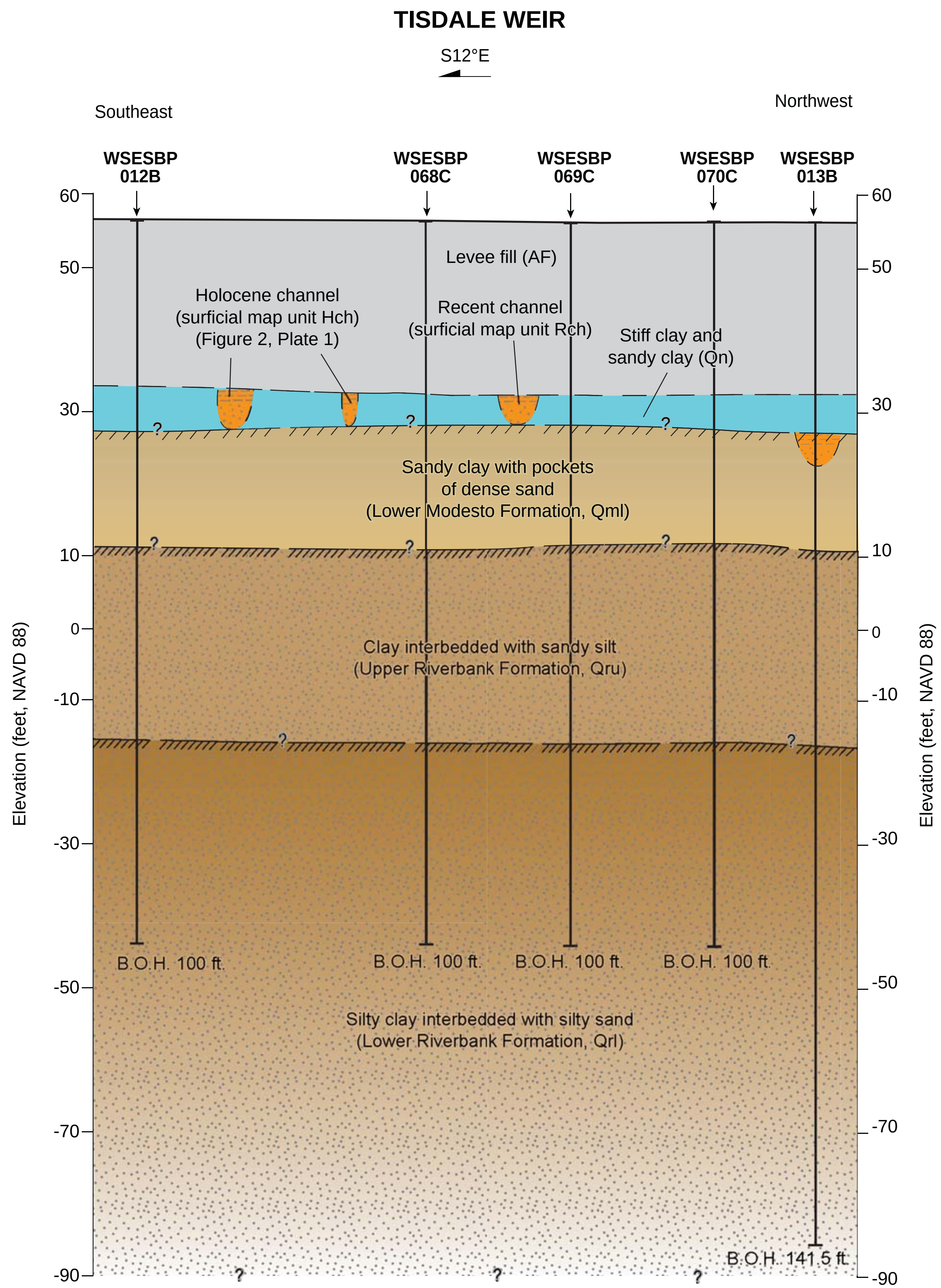
Figure 1



121°45'0"
121°40'0"
121°35'0"
39°5'0"
39°0'0"
38°55'0"
YUBA CITY
YUBA
SUTTER
AREA OF MAPPING
AREA OF MAPPING
Oswald Road
Cross section (see Figure 3)
WSESBP 013C
Cross section (see Figure 4)
WSESBP 012B
WSESBP 011B
Cross section (see Figure 5)
WSESBP 009C
SUTTER BYPASS
Feather River
Gilsizer Slough
Reclamation Road
Nelson Slough
WSESBP 001B
Cross section (see Figure 6)
WM0003 001S
99
113
Sources: NAIP, 2006
Projection: UTM Zone 10, NAD83
Explanation
Creek, slough
Canal, drain
Urban Project levee
Other levee
WSESBP 001B
Location of subsurface geotechnical exploration
N
0
1
2 mi
0
1
2 km



Notes: 1. See Figure 2 for location of cross section.
2. Surficial geologic units and contacts from this study and Helley and Harwood (1985).
3. Ground surface elevation from USGS Gilsizer Slough topographic map, 5-foot contour interval.



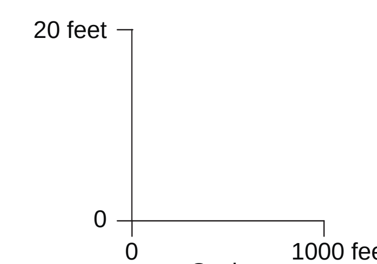
Explanation

Channel identified on surficial geologic map or as fining upward sequence of sediments in boreholes

Moderate paleosol (hardpan)

Strong paleosol (hardpan)

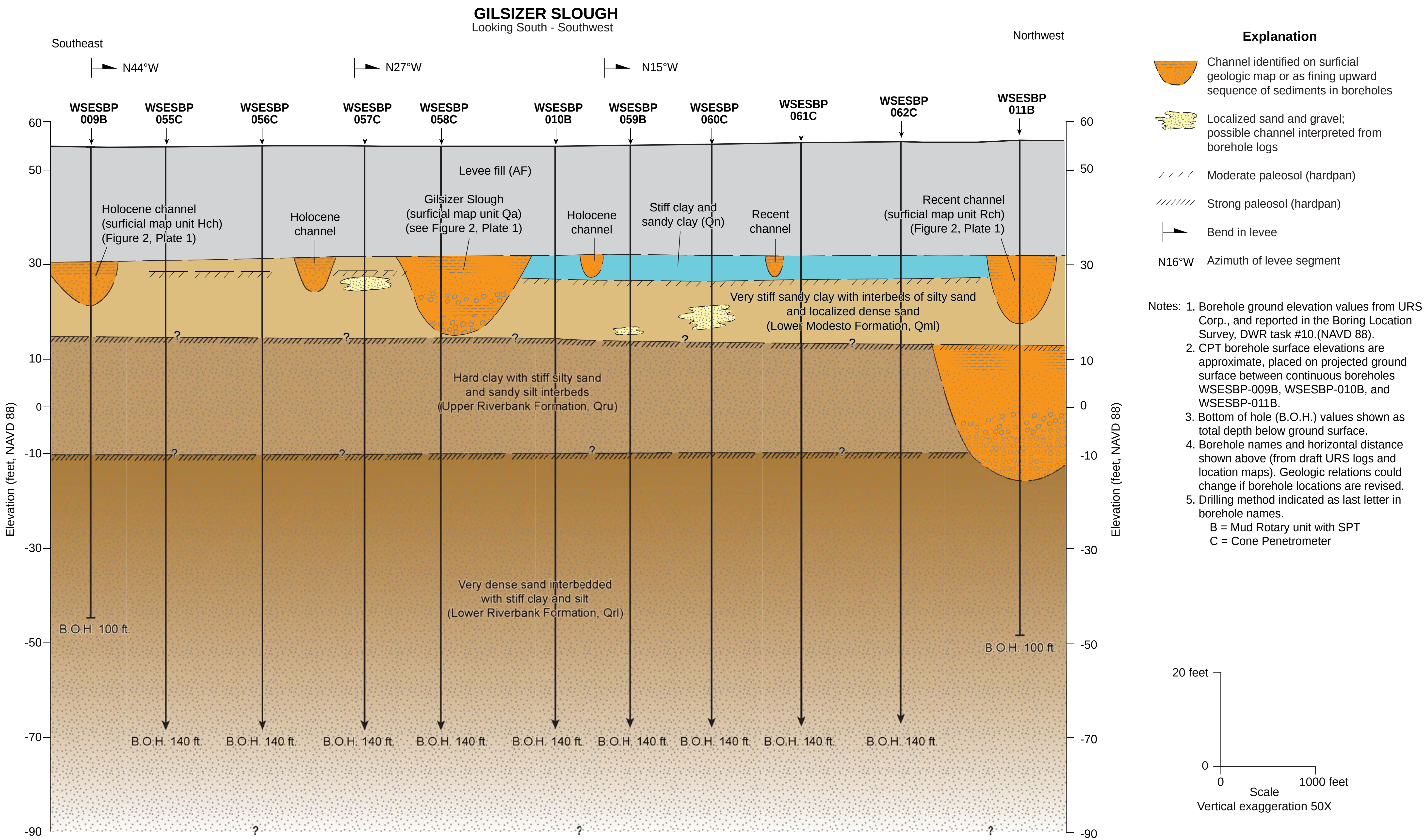
Notes:
1. Borehole ground elevation values from URS Corp., and reported in the Boring Location Survey, DWR task #10. (NAVD 88).
2. CPT borehole surface elevations are approximate, placed on projected ground surface between boreholes WSESBP_012B and WSESBP_013B.
3. Bottom of hole (B.O.H.) values shown as total depth below ground surface.
4. Borehole names and horizontal distance shown above from draft URS logs and location maps. Geologic relations could change if borehole locations are revised.
5. Drilling method indicated as last letter in borehole names.
   B = Mud Rotary unit with SPT
   C = Cone Penetrometer Test.



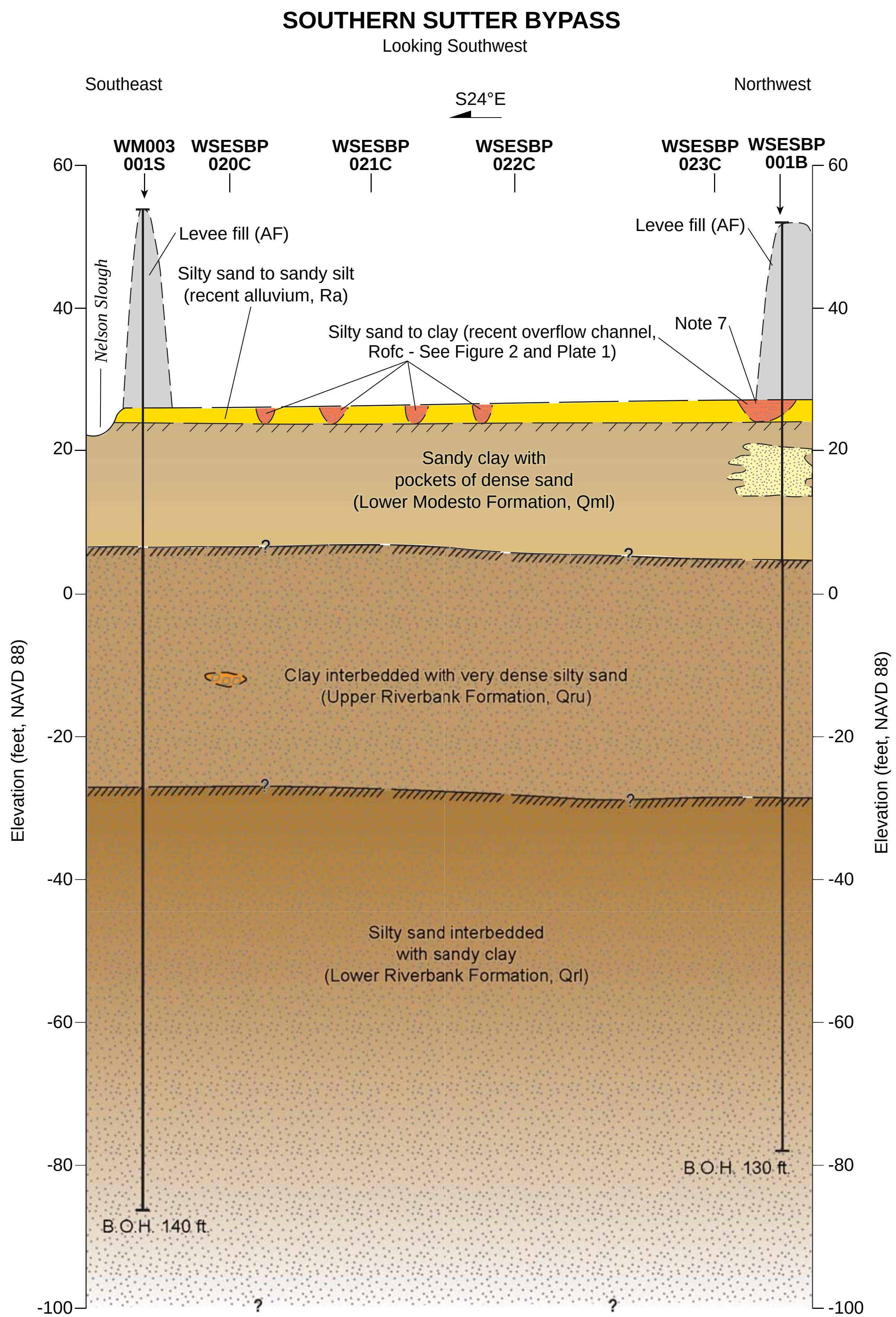
Scale
Vertical exaggeration 50X

GILSIZER SLOUGH

Looking South - Southwest



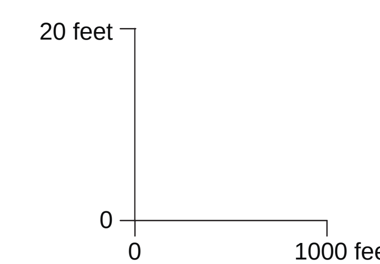
Notes:
1. Borehole ground elevation values from URS Corp., and reported in the Boring Location Survey, DWR task #10.(NAVD 88).
2. CPT borehole surface elevations are approximate, placed on projected ground surface between continuous boreholes WSESBP-009B, WSESBP-010B, and WSESBP-011B.
3. Bottom of hole (B.O.H.) values shown as total depth below ground surface.
4. Borehole names and horizontal distance shown above (from draft URS logs and location maps). Geologic relations could change if borehole locations are revised.
5. Drilling method indicated as last letter in borehole names.
   B = Mud Rotary unit with SPT
   C = Cone Penetrometer



Explanation

- Channel identified on surficial geologic map or as fining upward sequence of sediments in boreholes
- Localized sand and gravel; possible channel interpreted from borehole logs
- Moderate paleosol (hardpan)
- Strong paleosol (hardpan)
- Levee widths and side slopes are schematically shown

Notes:
1. Borehole ground elevation values from URS Corp., and reported in the Boring Location Survey, DWR task #10. (NAVD 88).
2. CPT borehole surface elevations are approximate, placed on projected ground surface between boreholes WM00_001S and WSESBP_001B.
3. Bottom of hole (B.O.H.) values shown as total depth below ground surface.
4. Borehole names and horizontal distance shown above from draft URS logs and location maps. Geologic relations could change if borehole locations are revised.
5. Drilling method indicated as last letter in borehole names.
   - B = Mud Rotary unit with SPT
   - S = Sonic vibracore
   - C = Cone Penetrometer Test.
6. Cone penetrometer borehole locations projected to the trend of this cross section.
7. Recent over flow channel shown beneath the northwestern levee intersects the levee at a sub-orthogonal angle. This conceptual cross section intersects the levee and the over flow channel at an oblique angle, as shown in the channel asymmetry.



Scale

Vertical exaggeration 50X

Explanation
Geologic contact; dashed where approximate, dotted where concealed, queried where uncertain; solid contacts have a resolution no better than about 30'.
Geomorphic Reaches Discussed in Text
Project Levee
WSESBP_001B Geotechnical borehole, approximately located.
W Water visible on 1937 aerial photography.
Geologic Units
HISTORICAL
AF Artificial fill; visible on 1937 aerial photography.
Rob Overbank deposits; sand, silt, and clay; deposited during high-stage water flow, overtopping channel banks.
Rcs Crevasse splay deposits; fine to coarse sand, with minor lenses of clay deposited from breaching of natural or artifical levees.
Rdf Distributary fan deposits; sand, silt and clay.
Rch Channel deposits; well sorted sands and fine gravels.
Rb Channel bar deposits; fine gravel, sand, and silt deposited in or along channel lateral margins.
Rdc Distributary channel deposits, trace gravel, sand, silt, and clay; channelized flow conducting sediment to floodplain.
Rofc Overflow channels; vertically stratified sand, silt, and clay in floodplain channels occupied primarily when high-stage water overtops channel banks.
Rsl Slough deposits; sand, silt and clay, fining upward facies, low-energy channel deposit.
Ra Alluvial deposits, undifferentiated; sand, silt, and minor lenses of fine gravel.
HOLOCENE
Hdf Distributary fan deposits; sand, silt and clay.
Hch Channel deposits; sorted sands and silts; fining upward.
Hb Channel bar deposits; fine sand, and silt deposited in or along channel lateral margins.
Hdc Distributary channel deposits, sand, silt, and clay.
Hsl Slough deposits; sand, silt and clay, fining upward facies, low-energy channel deposit.
Ha Alluvial deposits; undifferentiated; sand, silt, and minor lenses of gravel; under cultivation in 1937.
Qa Alluvial deposits, undifferentiated; sand, silt, and minor lenses of gravel; under cultivation in 1937.
Qn Basin deposits; fine sand, silt and clay, dark yellow to dark yellowish brown, under cultivation in 1937.
Qs Marsh deposits; silt and clay, likely organic-rich; perennially or seasonally submerged on 1937 photography.
PLEISTOCENE
Qmu Modesto Formation; upper member; unconsolidated gravel, sand, silt, and clay.
Qml Modesto Formation; lower member; unconsolidated to semi-consolidated gravel, sand, silt and clay.
Qru Riverbank Formation; upper member, semi-consolidated to consolidated gravel, sand, silt and minor clay.
Qrl Riverbank Formation; lower member; consolidated gravel, sand, silt, and clay, generally associated with strong duripan horizon.
Stratigraphic Correlation Chart
Time
Depositional Environment
Epoch
Channel deposits
Floodplain and alluvial-fan deposits
Flood basin deposits
Cultural deposits
Historical
Rch
Rdc
Rsl
Rofc
Ra
Rcs
Rdf
Rob
Qa
Qs
Qn
AF
Holocene
Hch
Hdc
Hb
Hsl
Ha
Hdf
Latest Pleistocene
Qmu
Qml
Pleistocene
Qru
Qrl
1:20,000
0 0.5 1 Miles
0 0.5 1 Kilometers
N
Map projection: UTM NAD83 Zone 10N
Topo base USGS quadrangles
Plate 1 - Surficial Geologic Map of the Sutter Bypass Area
WLA
WILLIAM LETTIS & ASSOCIATES, INC.
Walnut Creek, CA
Sutter_Bypass_MGT.mxd
09/04/2009
Geologic Mapping by J. Pearce and A. Streig
Digital Cartography by M. Ticci

Part C.4

URS Supplemental Geotechnical Data Report (2010), Appendix O, Volume 4

APPENDIX O

Geomorphology Report

WLA
WILLIAM LETTIS & ASSOCIATES, INC.
1777 Botelho Drive, Suite 262, Walnut Creek, California 94596
tel (925) 256-6070 fax (925) 256-6076

September 8, 2009

Mr. Juan Vargas
URS Corporation
2870 Gateway Oaks Drive, Suite 150
Sacramento, CA 95833

RE: Surficial geologic mapping and geomorphic assessment, California Department of Water Resources Urban Levees Project, Southern Feather River, Sutter County, California

Dear Mr. Vargas:

This memorandum presents the surficial geologic mapping and preliminary geomorphic assessment of the southern Feather River study area, for the California Department of Water Resources (DWR) Urban Levees Project geotechnical characterization. The goal of this mapping and geomorphic assessment is to provide information on the type and distribution of surface and shallow subsurface deposits that likely underlie the project levees along the western bank of the Feather River. The purpose of this study is to develop spatially-continuous geologic data and a conceptual model that provides a framework for stratigraphic interpretations between widely-spaced subsurface explorations. A primary goal is to provide a geologic framework for the geotechnical assessment of potential levee underseepage. This memo presents the technical approach, surficial geologic map, conceptual geomorphic model, and initial results based on map analysis and preliminary review of Phase 1 geotechnical data.

We appreciated the opportunity to provide these geomorphic and geologic data and preliminary interpretations of the shallow stratigraphic conditions in the southern Feather River study area. Please do not hesitate to call either of the undersigned if there are any questions or comments.

Respectfully,

WILLIAM LETTIS & ASSOCIATES, INC.

Justin Pearce

Justin Pearce, C.E.G. 2421
Senior Geologist

Ashley R. Streig

Ashley Streig
Senior Staff Geologist

Keith Kelson

Keith Kelson, C.E.G. 1610
Principal Geologist

1.0 Approach

The approach to developing a surficial geologic map of the southern Feather River project area (Figure 1, Plate 1) consisted of analysis of the following data: Aerial photography (black and white stereo-pairs taken in 1937, ~1:20,000-scale); early USGS topographic maps (i.e., 1911); published surficial geologic maps (Helley and Harwood, 1985); early and modern soil survey maps (Strahorn et al., 1909; Lytle, et al., 1988); and other maps and documents (Busacca et al., 1989). Synthesis of these data allow for the development of a detailed surficial geologic map that provides an initial understanding of primary geomorphic processes that have acted in the study area during recent and historical geologic time. Through this mapping, primary geomorphic features and associated surficial geologic deposits are identified, such as abandoned paleochannels, channel deposits, floodplain deposits, basin deposits and other features commonly associated with surficial deposits with large active river systems. Knowledge of fluvial processes and the ability to recognize depositional environments in the geologic record are key to identifying locations along levees where underseepage is most likely to occur (Llopis et al., 2007).

The surficial geologic map was developed at the nominal scale of the aerial photography (1:20,000). This scale establishes the resolution of the map (Plate 1), such that analysis of the map data at a more detailed scale than 1:20,000 may introduce uncertainties beyond the original resolution of the data. The map unit boundaries shown on the surficial geologic map should be considered approximate, and accurate within 30 feet on either side of the line shown on the map. The 1937 aerial photographs are the primary data set for interpreting the surficial geologic deposits because: (1) they are the oldest high-quality images that pre-date much of the urbanization and landscape alteration within present-day Sutter County (i.e. Figure 2); and, (2) these data represent a close approximation to the surficial deposits that were likely present at the ground surface prior to the construction of the levees. The 1937 photographs generally were taken in late summer or early autumn (i.e., August). By 1937, the area had experienced moderate cultivation that locally obscures geomorphic conditions. However, integration of data from the 1937 photography, old and recent topographic maps, geologic maps, soil surveys and historical documents provides sufficient information to delineate many of the pre-historical and historical surficial deposits in detail. Taken together, these data provide key insights to the characteristics of shallow deposits beneath the levees, as well as the geomorphic processes responsible for their distribution.

Additional floodplain deposition may have occurred after 1937, due to flood overflows, levee overtopping, or localized levee failure. A time series analysis that interprets successive aerial photographs taken after major flood events (i.e., USDA, black and white stereo-pairs taken in 1958, ~1:20,000-scale) or known local levee failures (i.e., 1986) may reveal additional information on surficial deposits in the southern Feather River area. Such analyses are beyond the scope of this study. The data and interpretations presented herein address the primary goal of characterizing the type and distribution of deposits likely present directly beneath the project levees.

1.1 Report Preparation Quality Control

The surficial geologic map data and geomorphic interpretations presented in this memorandum were subject to quality control and quality assurance procedures as required by the Levee Geotechnical Evaluation Project Management Plan (PMP). The surficial geologic map data developed by this study were reviewed for accuracy and completeness through an internal review and an independent technical review by Dr. Janet Sowers of WLA. Results of QA/QC review were documented using PMP Exhibit 2.2-3 (Independent Technical Review Report) and are kept on file according filing control plan. Subsurface data shown on diagrams were provided as draft information, and were not verified for accuracy or completeness by this study.

2.0 Geologic Setting

The southern Feather River study area lies in the Central Sacramento Valley, between the Coast Ranges to the west and the Sierra Nevada foothills to the east. Feather River drains the western slope of the Sierra Nevada, and emerges from the mountains south of the Thermalito Afterbay (Figure 1). The river flows southward from the Thermalito Afterbay, over middle-to late Pleistocene dissected alluvium derived from the Sierra Nevada. The regional land surface is nearly flat, with a gentle west-southwest slope that flattens out south of the Sutter Buttes, in Sutter Basin. The Feather River is entrenched into middle to late Pleistocene semi-consolidated sediments. Holocene alluvium deposited by the Feather River is present between the present-day levees, inset to the older formations, as well as on the western floodplain as subdued natural levees. The river trends roughly south until its confluence with the Bear River, where it curves
to the southwest (Figure 1). The Feather River lies east of, and is a tributary to the Sacramento River, converging near the town of Nicolaus (Figure 1). A primary influence on the historic processes in the river system was the hydraulic mining that began in the 1850's. Mining occurred through the early 1900's in the Feather, Yuba and Bear River watersheds, and abruptly introduced large quantities of sediment, drastically changing the geomorphic characteristics of these river systems (DWR, 2004; Ellis, 1939). Aggradation within the stream channel was a primary response to the introduction of substantial mining debris (James, 1999), consequently young alluvial deposits are common throughout the study area.

3.0 Surficial Geologic Mapping

Previous geologic mapping in the study area along the Feather River and surrounding areas generalize the surficial deposits as: Quaternary Alluvium (Qa) and Quaternary stream channel deposits (Qsc) within and proximal to the modern Feather River channel, (Helley and Harwood, 1985). These map units are considered Holocene age (less than 11,000 years old). Late Quaternary Modesto Formation (Qmu, Qml) is mapped along the western margin of the floodplain. These map units were delineated by Helley and Harwood (1985) at a regional scale (i.e., 1:62,500). The current analysis of the Feather River uses this geologic framework as a basis for more detailed mapping of late Holocene alluvium and geomorphic features (Plate 1).

The surficial geologic map units within the southern Feather River study area are described below, in order from oldest to youngest. Surficial geologic mapping for this study subdivides these map units and delineates individual deposits based on relative age and depositional process or environment (Plate 1). The map units depicted on Plate 1 are based primarily on analysis of 1937-vintage photography, and thus the map essentially is a "snapshot" of geologic conditions at this time.

The oldest unit exposed along the Feather River is the lower member of the Riverbank Formation (Qrl) of Helley and Harwood (1985). This unit is a highly dissected alluvial surface with textures of weathered gravel, sand and silt with strong soil-profile development. The Riverbank Formation is semi-consolidated, and is associated with the presence of a well-developed hardpan (or, duripan) layer that is a product of soil-forming processes over substantial geologic time. This hardpan layer reflects an ancient land surface that locally is buried by younger deposits. The Riverbank Formation is late to middle Pleistocene in age, and is estimated to be 130,000 to 450,000 yrs old (Helley and Harwood, 1985). The upper member is unconsolidated dark brown to red alluvium consisting of gravel, sand, silt and minor clay (Busacca et al., 1989, Helley and Harwood, 1985).

The Modesto Formation is divided into two members, a lower (older) unit that is latest Pleistocene in age (about 29,000 to 49,000 years old), and consists of unconsolidated slightly weathered gravel, sand, silt and clay. The upper member, a younger unit, is latest Pleistocene age (circa 12,000 to 26,000 years old) (Helley and Harwood, 1985). This unit (Qmu) is composed of sand, silt, and some gravel, comprising river channel and floodplain deposits, and is associated with a moderate amount of secondary (pedogenic) clay accumulation. This clay-rich horizon may form laterally continuous zones of low hydraulic conductivity, and may extend across boundaries between coarse and fine-grained strata within the latest Pleistocene alluvium. Soils on the Modesto Formation deposits include the Gridley loam of Strahorn et al. (1909) and the Conejo complex of Lytle et al. (1988).

Latest Holocene deposits overlie or are inset into the Modesto Formation, and are categorized as channel, floodplain, and basin deposits (Plate 1). Channel deposits include Holocene channels (Hch), distributary channels (Hdc), overflow channels (Hofc), sloughs (Hsl), in-stream or lateral bars (Hb), and meander scrolls (Hms). These deposits likely consist of fine to coarse sand, silty sand, and clayey sand, with trace fine gravel. Holocene channel deposits (Hch), which are present along Gilsizer Slough and the western floodplain as secondary channels, contain fining-upward sequences of sand, silt and clay. Overflow channels (Hofc) transport water across the land surface during high flow stages toward Sutter Basin. Networks of sloughs wander across the distal floodplain, and are likely filled with a fining-upward sequence of silt and clay (map unit Hsl). These deposits are associated with former channels, and generally are present landside (outboard) of the present-day human-made levees.

Holocene floodplain deposits include crevasse splays (Hcs), distributary fans (Hdf), and overbank deposits (Hob). Crevasse splays (Hcs) are sandy deposits that form from breaching of river banks or natural levees. Distributary fan deposits (Hdf) occur when water and velocity within a distributary channel decreases, can no longer transport its sediment load, and sediment is laid down on the floodplain. Overbank sediments are formed by localized overtopping of river banks or natural levees, subsequent deposition from shallow sheet flow or standing water. Basin deposits occur on the distal floodplain and include undifferentiated basin deposits (Qn), and marsh deposits (Qs). Basin and marsh deposits are present in the topographically low areas west of the present-day natural levees along the Feather River. These deposits consist of fine sand, silt, and clay laid down in a relatively low-energy depositional environment. Soils developed on these deposits are the Sacramento series silt loam, fine sandy loam, clay, Alamo clay loam adobe and Stockton clay adobe. Marsh deposits are generally saturated and are often underwater in the present-day environment. Undifferentiated Holocene and Quaternary alluvium (Ha and Qa, respectively) usually are proximal to the river channel, and this map unit is used in areas where geomorphic features are obscured or obliterated by historical (1937-era) agriculture or cultivation. The deposits within these agriculturally modified areas are assigned a relative age (Ha or Qa) based on overlapping and cross cutting relationships with the surrounding deposits as follows: Ha if the agriculture-modified area is mapped within or shown overlying Holocene deposits; or Qa where it is difficult to evaluate the surface age based on the nearby deposits. Soils associated with these, undifferentiated units (Qa) are the Sacramento silt loam and Sacramento fine sandy loam, (Strahorn et al., 1909), and the Columbia fine sandy loam of Lyle et al. (1988), which are weakly developed soils commonly developed on relatively young deposits.

Historical deposits mapped in the area include stream channel and floodplain deposits, as well as artificial fill deposits (L and SP) (Plate 1). Historical deposits are estimated to be less than 150 years old, dating from approximately 1800 to 1937. Historical stream channels (Rch), distributary channels (Rdc), and overflow channels (Rofc) within the floodplain are recently abandoned channels or reflect active channels with low water flow. Lateral bar deposits (Rb) and meander scrolls (Rms) are located adjacent to the present-day Feather River, and are generally present inboard (waterside) of the present-day Feather River levees. When the river overtops its banks, distributary channels (Rdc) and recent overflow channels (Rofc) transport water and sediment across the floodplain. These channel deposits likely consist of silt and sand with traces of gravel. The upper few feet of these deposits probably are filled with debris from upstream hydraulic mining activities. Historical sloughs transport low velocity water flow derived from distributary channels proximal to the Feather River onto the distal floodplain and into the Sutter Basin. Slough deposits (Rsl) likely consist of fining-upward silt and clay.

Historical flood plain deposits include crevasse splay (Rcs), distributary fan (Rdf), and overbank (Rob) deposits, which generally consist of a fining upward or episodic fining upward sequence of sand, silt, and clay. Historical overbank (Rob) deposits are slightly finer grained sand, silt, and clay deposited via sheet flow when the river is at flood-stage and overtops natural and artificial levees. These historical deposits are differentiated based on cross-cutting and superposition relationships relative to existing cultural deposits visible on the 1937 photographs. Historical alluvial deposits (Ra), generally located within the Feather River channel, consist of undifferentiated sand, silt, and minor lenses of gravel. Historical artificial fills (map units L and SP) are culturally-emplaced heterogeneous deposits, with varying amounts of clay, silt, sand, and gravel from local sources. These deposits include levee structures and canal levee systems (L), and some undifferentiated soil piles (SP), and are shown on the surficial geologic map where present and identifiable on the 1937 photography.

Mapping of historical and Holocene deposits shown on Plate 1 generally is consistent with early, less-detailed soil survey mapping along the western banks of the Feather River as areas of Gridley loam, Sacramento Series fine sand, sandy loam and silt loam soils (Strahorn et al., 1909). The Gridley loam occurs along the northern Feather River from Thermalito south to the confluence with the Bear River, and closely corresponds to the Modesto Formation of Helley and Harwood (1985). The relationship between the mapped surficial geologic units and the potential for underseepage is summarized below.

4.0 Geomorphic Conceptual Model

The preliminary conceptual model described here is based on general relationships among surface and subsurface geologic deposits along the Feather River, as described above and shown on Plate 1. This conceptual model provides a consistent basis for understanding the type and stratigraphy in the area.

Published geologic maps of the project area identify a complex series of westward aggrading alluvial fans and terraces derived from the Sierra Nevada, identified as the Riverbank and Modesto formations. The Riverbank Formation and Modesto Formation are semi-consolidated to unconsolidated deposits characterized by intraformational paleochannels and lateral and vertical stratigraphic complexity related to past fluvial processes and buried paleo-topography. The Riverbank Formation unconformably overlies the Laguna Formation, which is a deeply dissected alluvial surface (Busacca et al., 1989).

Subsurface deposits about 150 feet beneath the ground surface rest on a resistant volcanic tuff capped by interbedded alluvial gravel, sand and silt, interpreted as Pliocene-Pleistocene age Laguna Formation that represents a period of relatively stable landscape conditions (Helley and Harwood, 1985). The Laguna Formation is overlain by the Pleistocene Riverbank Formation, (very dense gravel deposits) that are, in turn, overlain by a medium dense sand and gravelly sand package of the latest Pleistocene Modesto Formation (Busacca et al., 1989). The upper member of the Modesto Formation is exposed at the ground surface adjacent to the western bank of the Feather River south of Marysville and Yuba City. The Modesto Formation is mantled by unconsolidated deposits of Holocene age that comprise most of the surficial geologic deposits along the western side of the Feather River (Plate 1).

Geomorphic evidence suggests that the Feather River system south of Yuba City may have been located west of its present course (Figure 3). The present-day Gilsizer Slough diverges from the modern Feather River directly north of Yuba City and trends southwestward toward the Sacramento River. Alluvial deposits of Gilsizer Slough are inset (i.e. incised) into the Modesto Formation from Yuba City southward. The ancestral Gilsizer Slough perhaps extended to as far as the Sacramento River (Figure 3), based on surficial mapping not included in this report, and inspection of topographic maps. The ancestral Gilsizer Slough deposits are related to discharges and sediment loads that were higher than present-day conditions, and perhaps is an ancestral course of the Feather River.

Surficial geologic deposits near the Yuba City airport indicate the Feather River occupied an intermediate position between ancestral and present locations. The river occupied an abandoned channel arm north of Shanghai Bend, located between Gilsizer Slough and the modern Feather River (Figure 3). From this point the river continued southward in nearly its present location. This paleochannel had a sharp, more exaggerated bend than the present-day channel at Shanghai Bend (Figure 2). The channel subsequently moved eastward, laterally backfilling and abandoning the meander above Shanghai Bend, and moved to the rivers' present location closer to Marysville. Today, Gilsizer Slough is a natural bypass for high water flow stages on the Feather River, in the area between Marysville and Yuba City (Ellis, 1939).

Surficial geologic mapping (Plate 1) shows differences in deposit type and distribution from north to south along the Feather River, which is associated with changes in watershed production of water and sediment, related geomorphic processes, soil profile development, and the underlying subsurface hardpan layer. These differences illustrate the diversity of past geomorphic processes along the river and, as a consequence, the type of geologic deposits at and near the ground surface. The surficial geologic map allows the delineation of reaches along the river within which geomorphic processes and their associated deposits appear to be relatively consistent.

Between Yuba City on the north to the confluence with the Sutter Bypass on the south, the southern Feather River consists of four major reaches, each having characteristic deposit types and distributions. The river reaches are numbered Southern Feather one through four (SF-I through SF-IV), sequentially from north to south (Plate 1, Figure 3). This report describes the surficial geologic characteristics of Reach SF-I, SF-II, SF-III and SF-IV of the southern part of the Feather River, extending from Yuba City, south to the confluence with the Sutter Bypass.

Reach SF-I, extends from the north end of Yuba City to the Yuba City airport, and is about 1.15 miles long (Plate 1, Figure 3). The Project levee along Reach SF-I trends roughly north-south, and overlies alluvial sediments deposited by the Feather River. In Yuba City the levee rests on Holocene deposits associated with Gilsizer Slough that are inset into the upper member of the Modesto Formation. The active Feather River channel is east of, and inset to these Holocene channel deposits (Figure 4).

The second reach of south Feather River project area, SF-II, extends from the Yuba City airport south to Shanghai Bend, and is about 2.9 miles long. Near the Yuba City airport, and south of the confluence of the Feather and Yuba Rivers, young channel deposits are inset against the Gilsizer Slough channel deposits (Plate 1). From the Yuba City airport, south to Epley Drive (about 1.5 miles), the levees overlie historical alluvium of mining debris origin, map unit Ra. From Epley Drive south to Shanghai Bend Road the levees (about 1.4 miles) overlie historical meander scrolls, map unit Rms, (Figure 2, Plate 1). The levee along this reach, SF-II, primarily overlies Holocene channel fill, historical alluvium and overbank deposits. These channels are likely filled with a fining-upward sequence of gravel, sand and silt, the upper few feet of these features are probably covered by a veneer of sediment derived from upstream hydraulic mining activities (Figure 4).

River Reach SF-III extends from Shanghai Bend on the north to just south of the confluence with Bear River, and is approximately 12 miles long (Plate 1). Along Reach SF-III, the active river floodplain is inset into the upper member of the Modesto Formation. Over geologic time, flooding has lead to the vertical accretion of overbank and crevasse splay deposits onto the Modesto Formation west of the Feather River. Overflow channels and related deposits (Rofc) are common along this reach of the river. Beginning at Shanghai Bend and continuing southward are seven overflow channels that range from approximately 100 to 200 feet wide. The Project levees overlie these channels in the area around Messick Road (Plate 1). A few overflow channels conduct water flow immediately landside of the levees, across a short distance between Shanghai Bend and Oswald Avenue, then converge with the Feather River. The overflow channels are slightly inset to the Modesto Formation, and based on borehole data from locations where these channels cross the Sutter Bypass, are probably 6 to 15 feet deep. These channels are likely filled with episodic fining upward sequences of silt, sand and gravel, representing multiple flood events on the Feather River. The upper few feet of these channels are probably filled with sediment from upstream historic hydraulic mining activities. The river channel widens considerably between Country Club Road (0.5 mile width) and Obanion Road (1 mile width), (Plate 1). Feather River meanders along the eastern edge of Abbott Lake, swings sharply southward into Star Bend, where the river is deflected eastward by a resistant knob of Modesto Formation (which forms Star Bend). Historical crevasse splay and overbank deposits overlie the Modesto Formation from Abbott Road to Star Bend Road, along the western edge of Abbot Lake (Figure 5). These crevasse splay deposits are likely filled with a fining-upward sequence of fine gravel, sand and silt, The upper few feet of these features are probably covered by a veneer of hydraulic mining sediment.

The southernmost reach, Reach SF-IV, extends from the area south of the confluence with the Bear River to the confluence of the Feather River and Sutter Bypass, and is roughly 4 miles long (Plate 1). The sediments underlying the levee along this reach are geomorphically complex, resulting from depositional convergence between the Feather River and Bear River. The Bear River channel deposits large amounts of sediment across the ground surface adjacent to the confluence. The Modesto and Riverbank Formations are exposed at the ground surface adjacent to natural levees immediately north of the Bear River confluence, and north of this reach (Plate 1). These formations are covered by historical alluvium, sourced from the Feather and Bear Rivers. Much of the historical activity along this reach is located near the levee at Laurel Avenue. Here, consisting eight distributary channels (Rdc), typically 90 feet wide but ranging from 45 to 190 feet wide, cross the floodplain in southwesterly orientations, terminating in geologically young distributary-fan sediments. These sediments, primarily consisting of fine to coarse sand and silt, probably were deposited as a result of increased sediment and water input contributed to the Feather River from the Bear River. Historically, the Feather River and the Bear River have aggraded from substantial mining debris input, thus reducing channel cross sectional area (i.e., James, 1999). This reduction of cross section area, coupled with the trajectory of flood flow from the Bear River watershed, resulted in water overtopping the Feather River channel banks, and depositing sediment onto the floodplain between the confluence of the Feather River and Sutter Bypass (Plate1).

5.0 Applications to the Urban Levee Project

Based on an initial analysis of surface geologic and geomorphic data, the levees bordering the western side of the Feather River from Yuba City to the Sutter Bypass, (Reaches SF-I, SF-II, SFIII and SF-IV) probably are underlain by a veneer of near-surface sandy deposits, or by buried channels that are inset into the Modesto Formation. The preliminary conceptual surface and subsurface geologic relationships as they relate to levee structures and potential underseepage along each reach of the river are described below. This study does not account for any existing seepage mitigation structures, i.e. slurry wall or cutoff wall, which may be present.

Reach SF-I contains the Gilsizer paleochannel deposits, this channel intersects the levees roughly 660 feet south of Lynn Way to Colusa Avenue (Plate 1). Along this length the levees are underlain by coarse channel deposits. These coarse grain deposits are likely laterally continuous and poorly consolidated and relatively highly permeable, and likely are susceptible to underseepage.

Levees along the reach SF-II are underlain by a Holocene paleochannel and historical meander scroll deposits (Figure 2, Plate 1). These deposits are coarse grained, laterally continuous and poorly consolidated, and likely are susceptible to underseepage. The presence of this paleochannel deposit suggests locally permeable material (channel fill) directly underlying the levees. Historical alluvium most likely of mining debris origin, blankets the Yuba City airport paleochannel and meander scroll deposits. The levees along this reach are underlain by a thick sequence of young, permeable alluvium of meander scroll deposits that are highly susceptible to seepage (Glynn and Kuszmaul, 2004).

Reach SF-III consists of coarse-grained avulsion deposits (overbank, crevasse splay and overflow channel deposits) overlying the Modesto Formation. Overflow channels (Rofc) are common along this reach, are relatively thin, slightly inset to the Modesto Formation and are filled with poorly consolidated sediments that may provide local pathways for underseepage. Individual shallow coarse deposits may be laterally discontinuous and may be separated by clayey interbeds (i.e. thin blankets). Local coarse deposits may be associated with higher likelihoods of levee underseepage. Deeper deposits probably consist of consolidated Modesto Formation with occasional small, but unconsolidated, overflow channel deposits incised into resistant strata.

Along Reach SF-IV the levee is underlain by laterally-continuous sandy deposits formed by distributary overbank fans and by the south flowing ancestral Feather River (Gilsizer Slough). These coarse-grained deposits likely are permeable and susceptible to underseepage. Near Laurel Avenue distributary channel deposits underlie the levees and may be relatively coarser than the surrounding alluvium.

6.0 Summary

Lateral and vertical variability in the shallow subsurface deposits has resulted from past geomorphic processes. Surficial geologic mapping along the south Feather River allows reach classifications within which conditions may be relatively consistent. The conceptual subsurface stratigraphic framework suggests that stratigraphic relationships may promote localized levee underseepage, given certain hydraulic conditions, particularly along reach SF-I and II. Further spatial analyses of the surficial geologic mapping and subsurface geotechnical exploration data are needed to better constrain and characterize areas that are most susceptible to underseepage in the study area.

7.0 Limitations

This geomorphic assessment and associated data interpretation have been performed in accordance with the standard of care commonly used as the state-of-practice in the geologic engineering profession. Standard of care is defined as the ordinary diligence exercised by fellow practitioners in this geographic area performing the same services under similar circumstances during the same time period.

Discussions of surface and subsurface conditions summarized in this technical memorandum are based on geologic interpretations of subsurface soil data at limited exploration locations available to this assessment through August of 2007. Variations in subsurface conditions may exist between exploration locations, and the project team may not be able to identify all adverse conditions in the levee and its foundation. This memorandum is for the use and benefit of DWR. Use by any other party is at their own discretion and risk.

8.0 References

Busacca, A.J, Singer, M.J., and Verosub, K.L., 1989, Late Cenozoic Stratigraphy of the Feather and Yuba Rivers Area, California, with a Section on Soil Development in Mixed Alluvium atHoncut Creek, USGS Bulletin 1590-G.

Department of Water Resources (DWR), 2004, SP-G2: Effects of Project Operations on Geomorphic Processes Downstream of Oroville Dam, Task 6 – Channel Meanders and Bank Erosion Monitoring, Oroville Facilities Relicensing FERC Project No. 2100, July.

Ellis, W.T., 1939, Memories: My Seventy-two Years in the Romantic County of Yuba, California (Memoirs of Marysville Levee Commissioner), p.103.

Helley, E.J., and Harwood, D.S., 1985, Geologic map of the late Cenozoic deposits of the Sacramento Valley and Northern Sierran foothills, California; 1:62,500, USGS Map File MF-1790.

Glynn, M.E., and Kuszmaul, J., 2004, Prediction of Piping Erosion Along Middle Mississippi River Levees – An Empirical Model; Technologies and Operational Innovations for Urban Watershed Networks Research Program; US Army Corps of Engineers, Engineer Research and Development Center, Geotechnical and Structures Laboratory publication ERDC/GSL TR-04-12.

James, A., 1999, Time and the Persistence of Alluvium: River Engineering, Fluvial Geomorphology, and Mining Sediment in California; Geomorphology, v. 31, p. 265 – 290.

Llopis, J.L., Smith, E.W., and North, R.E., 2007, Geophysical Surveys for Assessing Levee Foundation Conditions, Sacramento River Levees, Sacramento, CA; US Army Corps of Engineers, Engineer Research and Development Center, Geotechnical and Structures Laboratory publication ERDC/GSL TR-07-21, 61p.

Lytle, D.J., Kurowski, R.G., Whiting, M.L., Vinson, E.N., Vonich, P.W., Hansen, R.W., 1988, Soil Survey of Sutter County, California, 1:24,000, USDA Soil Conservation Service.

Strahorn, A.T., Mackie, W.W., Holmes, L.C., Westover, H.L., Van Duyne, C., 1909, Soil Survey of the Marysville Area, California; 1:62,500, USDA Bureau of Soils.

USGS, Gilsizer Slough topographic quadrangle, surveyed 1909, published 1911; map scale 1:31,680, five foot contour interval.

USGS, Marcuse topographic quadrangle, surveyed 1906, published 1910; map scale 1:31,680, five foot contour interval.

USGS, Nicolaus topographic quadrangle, surveyed 1908, published 1910; map scale 1:31,680, five foot contour interval.

USGS, Ostrom topographic quadrangle, surveyed 1909, published 1911; map scale 1:31,680, five foot contour interval.

USGS, Sutter topographic quadrangle, surveyed 1909, published 1911; map scale 1:31,680, five foot contour interval.

USGS, Yuba City topographic quadrangle, surveyed 1909, published 1911; map scale 1:31,680, five foot contour interval.

USGS, Gilsizer Slough topographic quadrangle, published 1952, photo revised 1973; map scale 1:24,000, five foot contour interval.

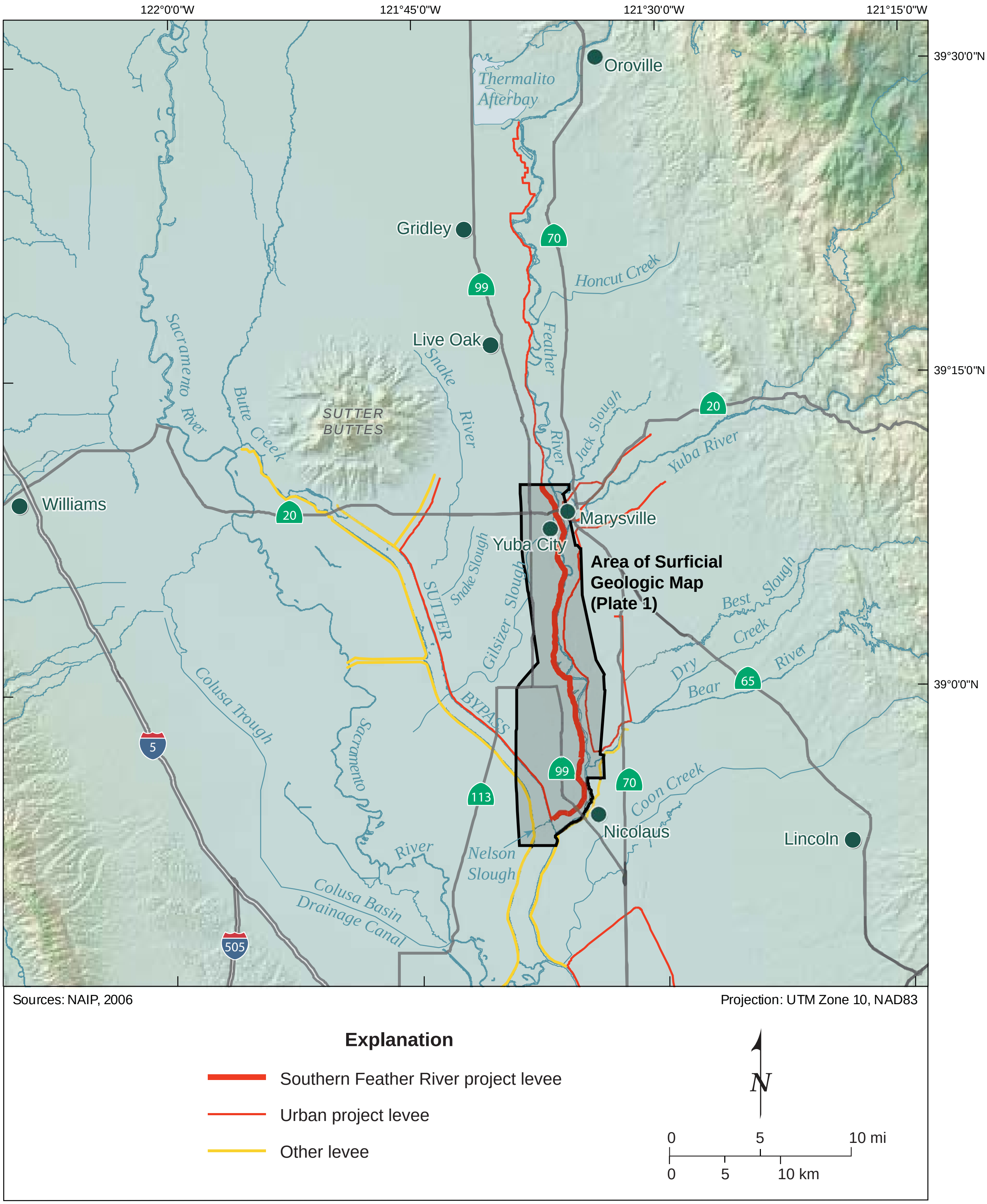
USGS, Nicolaus topographic quadrangle, published 1952, remapped 1992; map scale 1:24,000, five foot contour interval.

USGS, Olivehurst topographic quadrangle, published 1952, photo revised 1973; map scale 1:24,000, five foot contour interval.

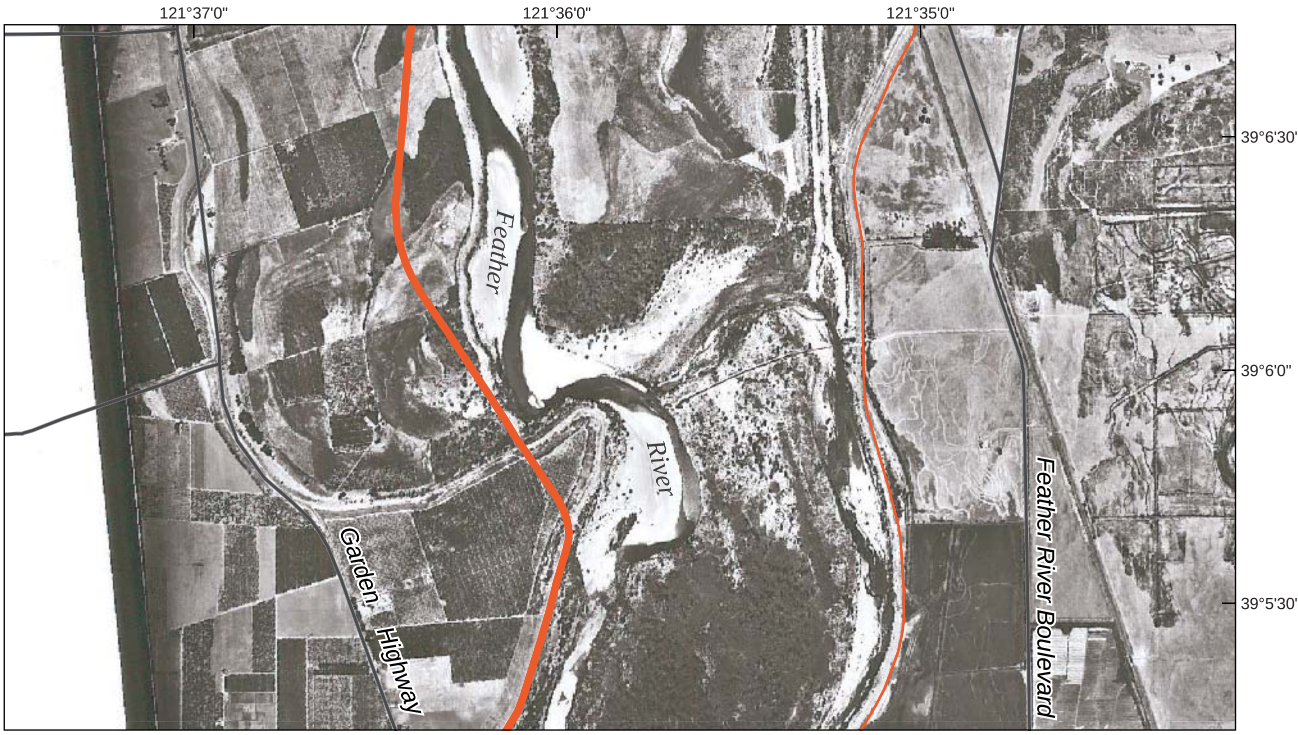
USGS, Sutter topographic quadrangle, published 1952, photo revised 1973; map scale 1:24,000, five foot contour interval.

USGS, Sutter Causeway topographic quadrangle published 1952, photo revised 1973; map scale 1:24,000, five foot contour interval.

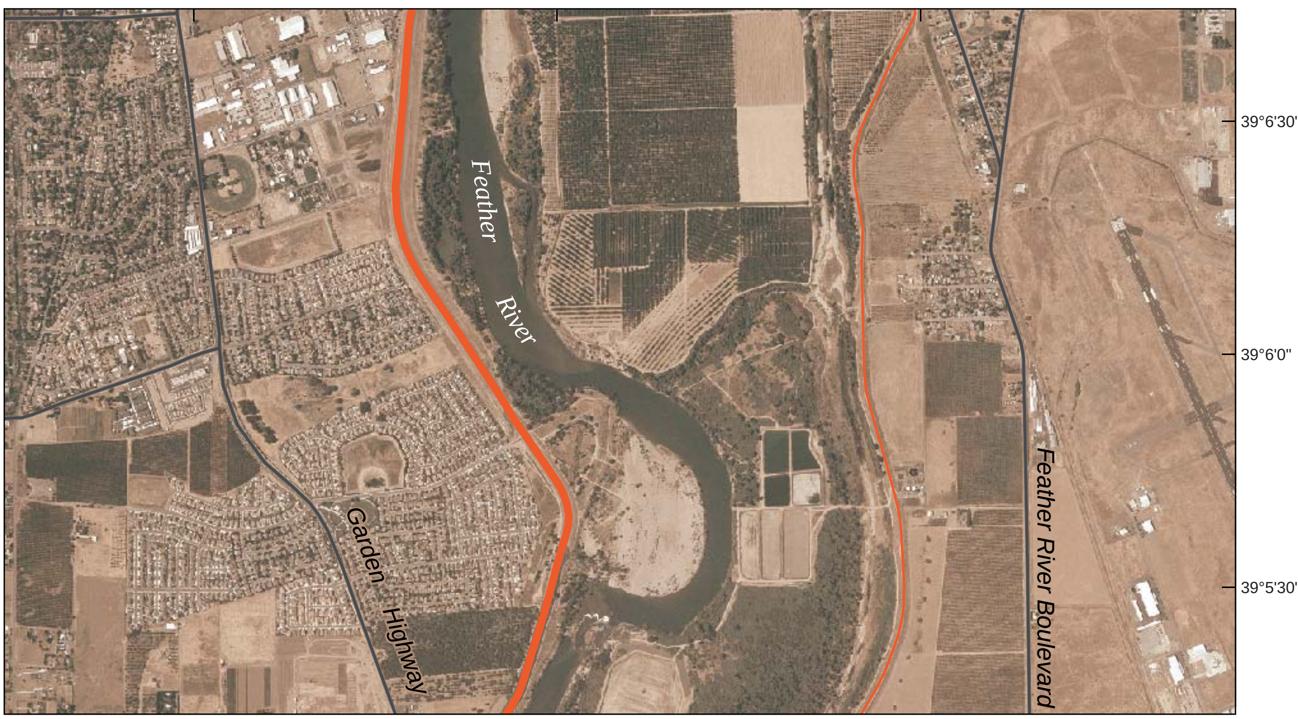
USGS, Yuba City topographic quadrangle, published 1952, photo revised 1973; map scale 1:24,000, five foot contour interval.



Map of Central Valley near Sutter Buttes, California



A. 1937 USDA Air Photo



B. 2006 NAIP Ortho Imagery

Explanation

- Southern Feather River project levee
- Urban project levee
- Major road

N

0 5 10 mi

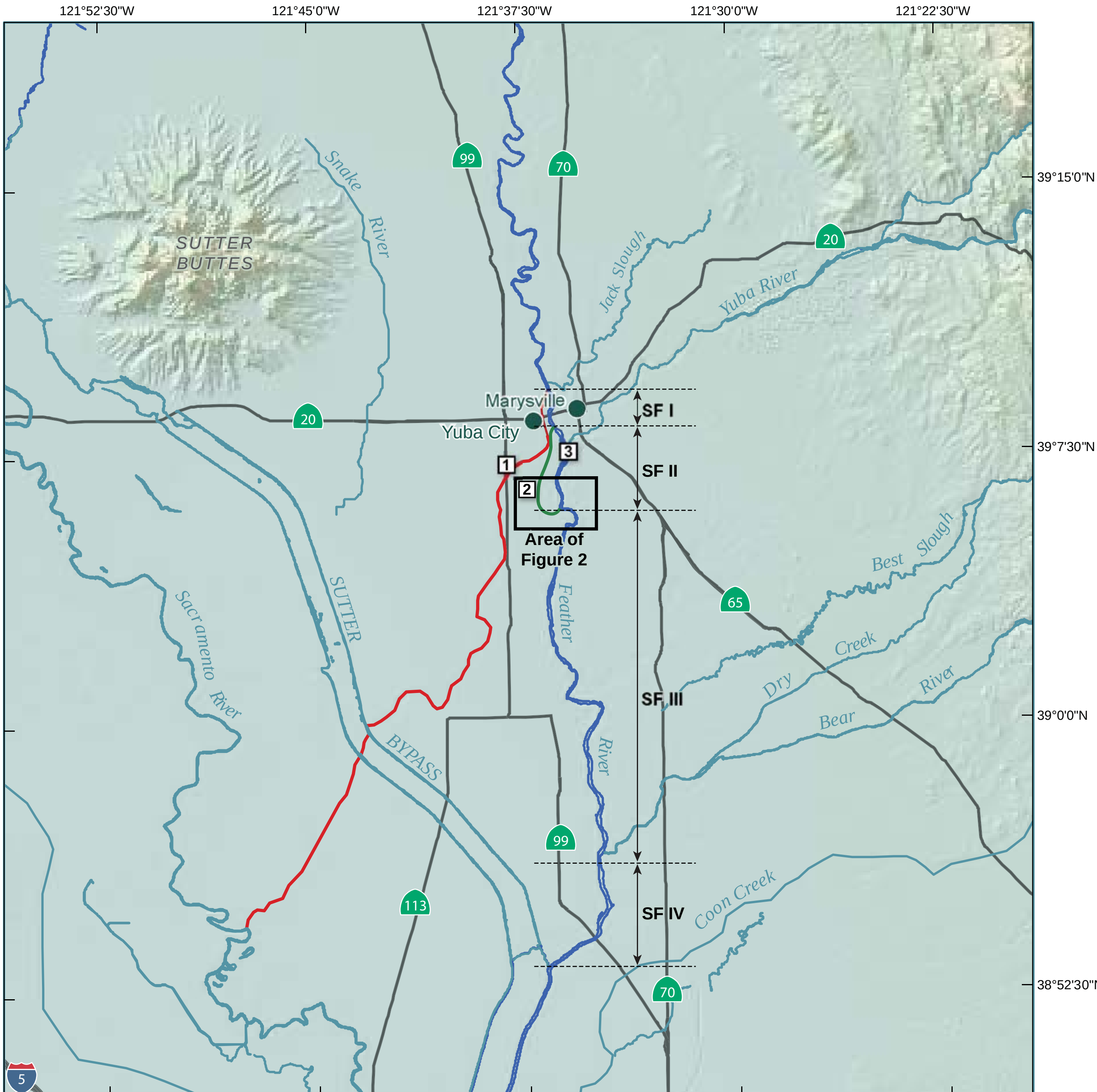
0 5 10 km

WLA

Aerial Imagery of the Feather River at Shanghai Bend

DWR URBAN LEVEE PROJECT

Figure 2



Source: ESRI, 2006

Projection: UTM Zone 10, NAD83

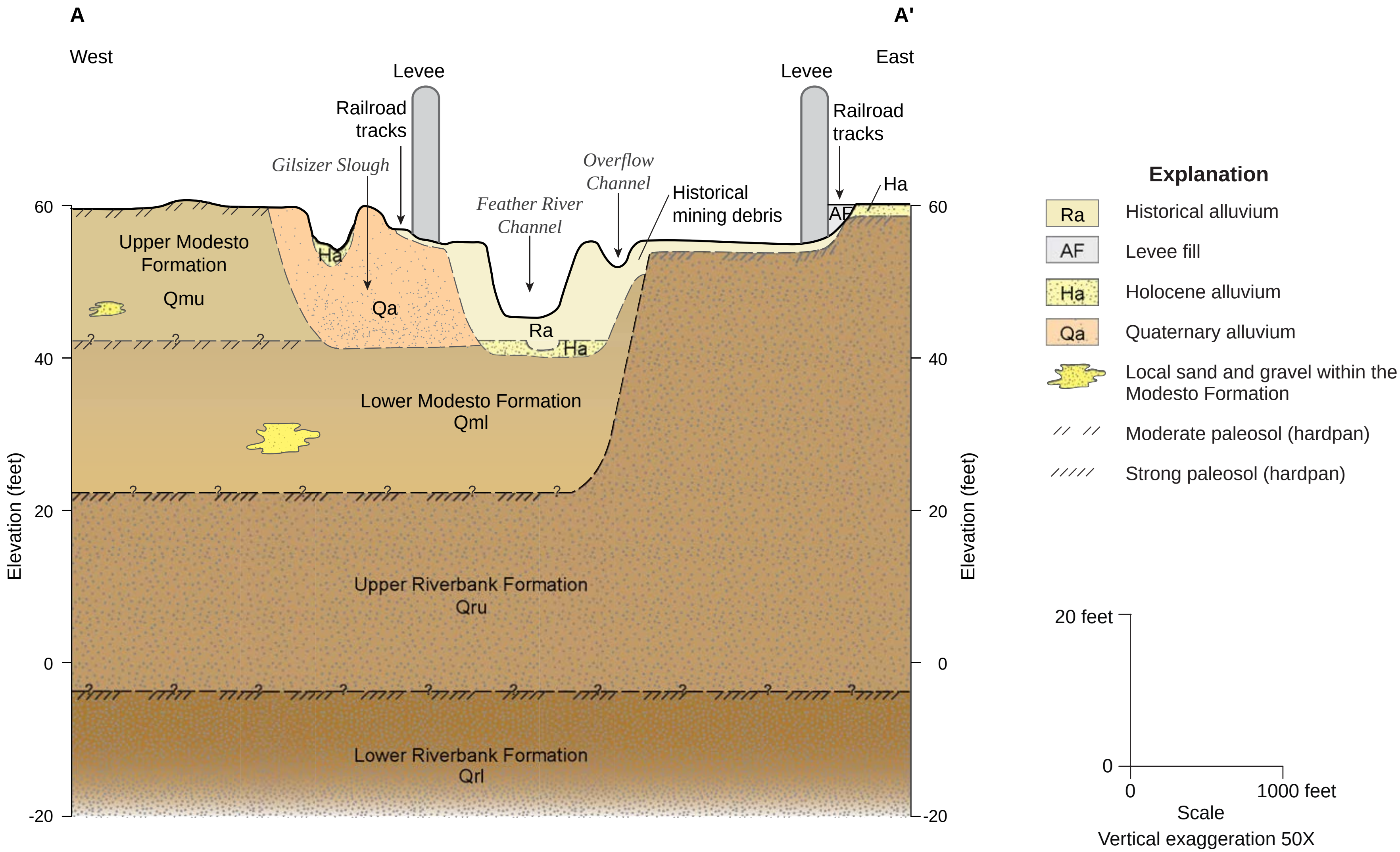
Explanation

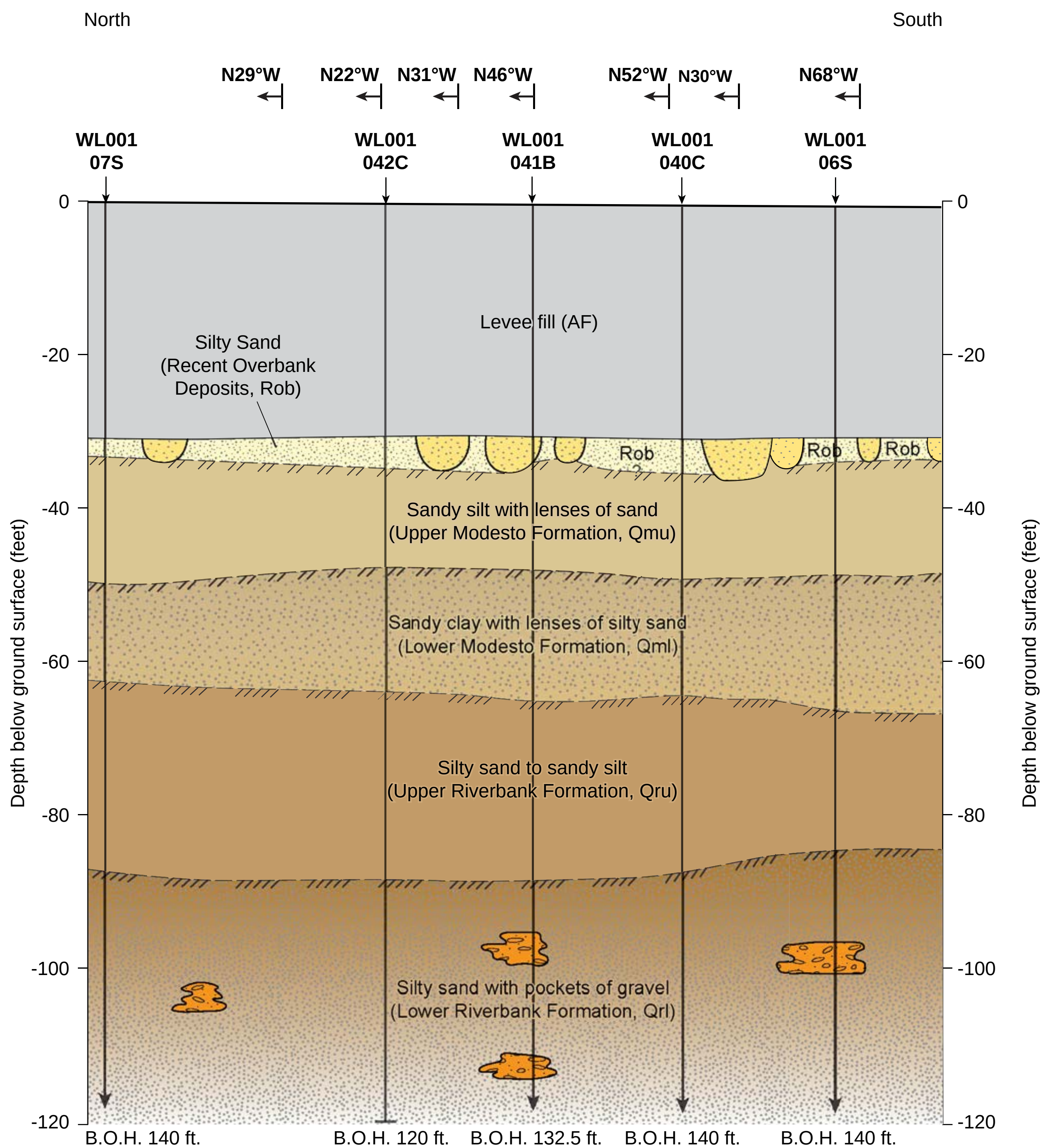
3	Modern Feather River Channel
2	Abandoned arm of the Feather River
1	Ancestral Feather River Channel (Gilsizer Slough)
SF I	Reach of Southern Feather River Study Area

N

0 5 mi

0 5 km

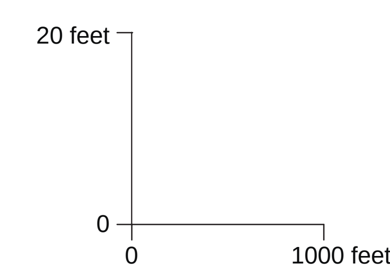

A
A'
West
East
Levee
Levee
Railroad tracks
Railroad tracks
Gilsizer Slough
Overflow Channel
Feather River Channel
Historical mining debris
Ha
AF
Upper Modesto Formation
Qmu
Qa
Ha
Ra
Ha
Lower Modesto Formation
Qml
Upper Riverbank Formation
Qru
Lower Riverbank Formation
Qrl
Elevation (feet)
Elevation (feet)
60
40
20
0
-20
Explanation
Ra Historical alluvium
AF Levee fill
Ha Holocene alluvium
Qa Quaternary alluvium
Local sand and gravel within the Modesto Formation
Moderate paleosol (hardpan)
Strong paleosol (hardpan)
20 feet
0
0
1000 feet
Scale
Vertical exaggeration 50X



Explanation

- Recent crevasse splay, surficial geologic map unit Rcs
- Local sand and gravel within the Riverbank Formation
- Moderate paleosol (hardpan)
- Strong paleosol (hardpan)
- N46°W Bend in Section

Notes:
1. See Plate 1 for location of cross section.
2. Surficial geologic units and contacts from this study and Helley and Harwood (1985).
3. Bottom of hole (BOH) values shown as total depth below ground surface.
4. Borehole names and horizontal distance shown above from draft URS logs and location maps. Geologic relations could change if borehole locations revised
5. Drilling method indicated as last letter in borehole names:
   S = Sonic Vibracore;
   C = Cone Penetrometer Test;
   B = Mud Rotary with SPT



Scale

Vertical exaggeration 50X


Plate 1 - Surficial Geologic Map of the Feather River, Southern Section
This map shows surficial geologic deposits and levees as they existed in 1937. Map units and boundaries are drawn by interpretation of historical aerial photography supplemented by data from historical maps and surveys. For reference, the mapping is superimposed on modern U.S. Geological Survey topographic base map prepared in 1952 and photo revised in 1973. See accompanying report for complete descriptions of map units, process descriptions and methodology.
Explanation
Geologic contact; dashed where approximate, dotted where concealed, queried where uncertain; solid contacts within 30' of line shown on map.
SF-II
Geomorphic Reaches Discussed in Text
Project Levees
A
A'
Cross Section
WSL001_006S
Borehole locations from URS, Corp; locations from Sutter P2 Boring Locations, Region 1 Northern Area map.
W 1937
Water bodies, circa 1937.
BP
Borrow pits present in 1937.
Geologic Units
HISTORICAL
L Levees (artificial fill), circa 1937.
SP Spoils pile (artificial fill), circa 1937.
Rob Overbank deposits; sand, silt, and clay; deposited during high-stage water flow, overtopping channel banks.
Rcs Crevasse splay deposits; fine to coarse sand, with minor lenses of clay deposited from breaching of natural or artifical levees.
Rdf Distributary fan deposits; sand, silt and clay.
Rch Channel deposits; well sorted sands and fine gravels.
Rms Channel meander scroll deposits; sand, silt and clay from lateral channel migration.
Rb Channel bar deposits; fine gravel, sand, and silt deposited in or along channel lateral margins.
Rcu Cut off channel (chute); occurs on insides of meander bends within the river channel; on flood plain – entrenchment of overflow channels into hydraulic mining debris.
Rdc Distributary channel deposits, trace gravel, sand, silt, and clay; channelized flow conducting sediment to floodplain.
Rofc Overflow channels; vertically stratified sand, silt, and clay in floodplain channels occupied primarily when high-stage water overtops channel banks.
Rsl Slough deposits; sand, silt and clay, fining upward facies, low-energy channel deposit.
Ra Alluvial deposits, undifferentiated; sand, silt, and minor lenses of fine gravel.
HOLOCENE
Hob Overbank deposits; sand, silt, and clay; deposited during high-stage water flow, overtopping channel banks.
Hcs Crevasse splay deposits; fine to coarse sand, with minor lenses of fine gravel deposited from breaching of natural or artifical levees.
Hdf Distributary fan deposits; sand, silt and clay.
Hofc Overflow channels; vertically stratified sand, silt, and clay in channels occupied when high-stage water overtops channel banks.
Hch Channel deposits; sorted sands and silts; fining upward.
Hb Channel bar deposits; fine sand, and silt deposited in or along channel lateral margins.
Hdc Distributary channel deposits, sand, silt, and clay.
Hsl Slough deposits; sand, silt and clay, fining upward facies, low-energy channel deposit.
Ha Alluvial deposits; undifferentiated; sand, silt, and minor lenses of gravel; under cultivation in 1937.
Qn Basin deposits; fine sand, silt and clay, dark yellow to dark yellowish brown, under cultivation in 1937.
Qs Marsh deposits; silt and clay, likely organic-rich; perennially or seasonally submerged on 1937 photography.
PLEISTOCENE
Qmu Modesto Formation; upper member; unconsolidated gravel, sand, silt, and clay.
Qml Modesto Formation; lower member; unconsolidated to semi-consolidated gravel, sand, silt and clay.
Qru Riverbank Formation; upper member, semi-consolidated to consolidated gravel, sand, silt and minor clay.
Qrl Riverbank Formation; lower member; consolidated gravel, sand, silt, and clay, generally associated with strong duripan horizon.
Stratigraphic Correlation Chart
Time
Depositional Environment
Epoch
Channel deposits
Floodplain and alluvial-fan deposits
Flood basin deposits
Cultural deposits
Historical
Rch Rdc Rb Rsl Rms Rofc Rcu
Qa Ra Rcs Rdf Rob
Qs Qn
L SP
Holocene
Hch Hdc Hb Hsl
Ha Hdf Hcs Hob Hofc
Latest Pleistocene
Pleistocene
Qmu
Qml
Qru
Qrl
SF-I
SF-II
SF-III
SF-IV
MARYSVILLE
YUBA CITY
1:20,000
N
0 0.5 1 Miles
0 0.5 1 Kilometers
Map projection: UTM NAD83 Zone 10N
Topographic base USGS quadrangles:
USGS, Gilsizer Slough topographic quadrangle, published 1952, photo revised 1973; map scale 1:24,000, five foot contour interval.
USGS, Nicolaus topographic quadrangle, published 1952, remapped 1992; map scale 1:24,000, five foot contour interval.
USGS, Olivehurst topographic quadrangle, published 1952, photo revised 1973; map scale 1:24,000, five foot contour interval.
USGS, Sutter topographic quadrangle, published 1952, photo revised 1973; map scale 1:24,000, five foot contour interval.
USGS, Sutter Causeway topographic quadrangle published 1952, photo revised 1973; map scale 1:24,000, five foot contour interval.
USGS, Yuba City topographic quadrangle, published 1952, photo revised 1973; map scale 1:24,000, five foot contour interval.
Plate 1 - Surficial Geologic Map of the Feather River, Southern Section
WLA
WILLIAM LETTIS & ASSOCIATES, INC.
Walnut Creek, CA
1881_URS_Feather_South.mxd
09/04/2009
Geologic Mapping by J. Pearce and A. Streig
Digital Cartography by M. Ticci

Part C.5

URS Supplemental Geotechnical Data Report (2010), Appendix O, Volume 5

APPENDIX O

Geomorphology Report

Surficial Geologic Maps and Geomorphic Assessment of the Sutter Study Area, Urban Levee Geotechnical Evaluation, Sutter and Butte Counties, California

Prepared for:

URS Corporation
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Prepared by:

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September 8, 2009

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September 8, 2009

Mr. Juan Vargas
URS Corporation
2870 Gateway Oaks Drive, Suite 150
Sacramento, CA 95833

RE: Surficial geologic mapping and geomorphic assessment, California Department of Water Resources Urban Levees Project, Northern Feather River, Sutter County, California

Dear Mr. Vargas:

This letter presents the surficial geologic mapping and preliminary geomorphic assessment of the northern Feather River study area, for the California Department of Water Resources (DWR) Urban Levees Project geotechnical characterization. The goal of this mapping and geomorphic assessment is to provide information on the type and distribution of surface and shallow subsurface deposits that likely underlie the project levees along the western bank of the Feather River between Thermalito Afterbay and Yuba City. The purpose of this study is to develop spatially continuous geologic map data and a conceptual model for stratigraphic interpretations between shallow boreholes. A primary goal is to provide a geologic framework for the geotechnical assessment of potential levee underseepage. This letter presents the technical approach, surficial geologic map, conceptual geomorphic model, and initial results based on map analysis and preliminary review of available Phase 1 geotechnical data.

We appreciated the opportunity to provide these geomorphic and geologic data and preliminary interpretations of the shallow stratigraphic conditions in the northern Feather River study area. Please do not hesitate to call any of the undersigned if there are any questions or comments.

Respectfully,

WILLIAM LETTIS & ASSOCIATES, INC.

Justin Pearce, C.E.G. 2421
Senior Geologist

Ashley Streig
Senior Staff Geologist

Keith Kelson, C.E.G. 1610
Principal Geologist

1.0 Introduction

This technical memorandum presents the results of surficial geologic mapping and geomorphic assessment along the north Feather River between Thermalito Afterbay and Yuba City, for the California Department of Water Resources Urban Levee program. The purpose of this study is to provide detailed information on the type and distribution of surface and shallow subsurface deposits that likely underlie the project levees, with respect to levee underseepage. This study involved integration and analysis of aerial photography, topographic, geologic, and soil maps, other historical documents, and review of readily available geotechnical exploration data. Synthesis of these data allowed us to assess the geomorphic processes responsible for the distribution of surficial deposits within the project area, and construct a preliminary conceptual model for stratigraphic interpretations. This technical memorandum is accompanied by the "Surficial Geologic Map of the Feather River, Northern Section".

1.1 Map and Report Preparation Quality Control

The surficial geologic map data and geomorphic interpretations presented in this memorandum were subject to quality control and quality assurance procedures as required by the Levee Geotechnical Evaluation Project Management Plan (PMP). The surficial geologic map data developed by this study were reviewed for accuracy and completeness through an internal review and an independent technical review by Dr. Janet Sowers of WLA. Results of QA/QC review were documented using PMP Exhibit 2.2-3 (Independent Technical Review Report) and are kept on file according filing control plan. Subsurface data shown on diagrams were provided as draft information, and were not verified for accuracy or completeness by this study.

2.0 Approach

The approach to developing a surficial geologic map of the northern Feather River project area (Figure 1, Plate 1) consisted of analysis of the following data:

- Aerial photography (black and white stereo-pairs taken in 1937, ~1:20,000-scale);
- early USGS topographic maps (i.e., 1911);
- published surficial geologic maps (Bussaca et al., 1989; Helley and Harwood, 1985; Creely, 1965);
- early and modern soil survey maps (Strahorn et al., 1909; Lytle, et al., 1988);
- other maps and documents (Page, 1985).

Synthesis of these data allow for the development of a detailed surficial geologic map that provides an initial understanding of primary geomorphic processes that have acted in the study area during recent and historical geologic time. Through this mapping, primary geomorphic features and associated surficial geologic deposits are identified, such as abandoned paleochannels, channel deposits, splay and overbank deposits and other deposits commonly associated with large active river systems. Knowledge of fluvial processes and the ability to recognize depositional environments in the geologic record are key to identifying locations along levees where underseepage is most likely to occur (Llopis et al., 2007).

The surficial geologic map was developed at the nominal scale of the aerial photography (1:20,000). This scale establishes the resolution of the map (Plate 1), such that display or analysis of the map data at a more detailed scale than 1:20,000 may introduce uncertainties beyond the original resolution of the data. The map unit boundaries shown on the surficial geologic map should be considered approximate, and accurate within 30 feet on either side of the line shown on the map. The 1937 aerial photographs are the primary data set for interpreting the surficial geologic deposits because: (1) they are the oldest high-quality images that pre-date much of the urbanization and landscape alteration within present-day Sutter and Butte Counties and, (2) these data represent a close approximation to the surficial deposits that were likely present at the ground surface prior to the construction of the levees. The 1937 photographs generally were taken in late summer or early autumn (i.e., August). By 1937, the area had experienced moderate cultivation that locally obscures geomorphic conditions. However, integration of data from the 1937 photography, old and recent topographic maps, geologic maps, soil surveys and historical documents provides sufficient information to delineate many of the pre-historical and historical surficial deposits in detail. Taken together, these data provide key insights to the characteristics of shallow deposits beneath the levees, as well as the geomorphic processes responsible for their distribution.

Additional floodplain deposition may have occurred after 1937, due to flood overflows, levee overtopping, or localized levee failure. A time series analysis that interprets successive aerial photographs taken after major flood events (i.e., USDA, black and white stereo-pairs taken in 1958, ~1:20,000-scale) or known local levee failures (i.e., 1986) may reveal additional information on surficial deposits in the northern Feather River area. Such analyses are beyond the scope of this study. The data and interpretations presented herein address the primary goal of characterizing the type and distribution of deposits likely present directly beneath the project levees that may be conducive to underseepage.

3.0 Geologic Setting

The northern Feather River study area lies in the central Sacramento Valley, between the Coast Ranges to the west and the Sierra Nevada foothills to the east. The Feather River drains the western slope of the Sierra Nevada, and emerges from the mountains south of Thermalito Afterbay (Figure 1). The river flows southward from Thermalito Afterbay, over middle –to late Pleistocene alluvium derived from the Sierra Nevada. The regional land surface is nearly flat, with a gentle west-southwest slope that flattens south of the Sutter Butte. The Feather River is entrenched into middle-to-late Pleistocene semi-consolidated sediments (i.e. Modesto Formation). Historical alluvium deposited by the Feather River is present between the modern levees, inset to the older geologic formations, and is present on the western floodplain as subdued natural levees that mantle the older geologic formations. In this study reach, west-flowing Honcut Creek is the only drainage tributary to the northern Feather River, with a confluence east of the town of Live Oak (Figure 1).

A primary influence on the historical processes in the river system was the hydraulic mining that began in the 1850's. Mining continued through the early 1900's in the Feather, Yuba and

Bear River watersheds, and abruptly introduced large quantities of sediment and drastically changed the geomorphic characteristics of these river systems (DWR, 2004; Ellis, 1939). Aggradation within the stream channels was a primary response to the introduction of substantial mining debris (James, 1999); consequently, post-1850 alluvial deposits are common throughout the study area.

4.0 Surficial Geologic Mapping

Previous geologic mapping along the northern Feather River and surrounding areas generalize the surficial deposits as: Quaternary alluvium (Qa) and Quaternary stream channel deposits (Qsc) are mapped within and proximal to the modern Feather River channel, (Bussaca et al., 1989; Helley and Harwood, 1985; Creely, 1965). These map units are considered Holocene in age (less than 11,000 years old). Late Pleistocene Modesto Formation (Qmu, Qml) is present as an escarpment along the western margin of the floodplain. These map units were delineated by Helley and Harwood (1985) at a regional scale (i.e., 1:62,500). The current analysis of the northern Feather River uses this geologic framework as a basis for more detailed mapping of Quaternary deposits and geomorphic features (Plate 1). The surficial geologic map units within the northern Feather River study area are described below, in order from oldest to youngest. Surficial geologic mapping for this study subdivides these general map units and delineates individual deposits based on relative age and depositional process or environment. The map units depicted on Plate 1 are primarily based on analysis of 1937 aerial photography, and thus the map essentially is a “snapshot” of geologic conditions at this time.

The oldest unit exposed along the Feather River is the lower member of the Riverbank Formation (Qrl) of Helley and Harwood (1985). The Riverbank Formation is a semi-consolidated, highly-dissected alluvial surface with textures of weathered gravel, sand and silt, and is associated with the presence of a well-developed hardpan (or, duripan) layer. This hardpan layer is a product of soil-forming processes over substantial geologic time, and reflects an ancient land surface that locally is buried by younger deposits. The Riverbank Formation is late to middle Pleistocene in age, and is estimated to be 130,000 to 450,000 yrs old (Helley and Harwood, 1985). The upper member (map unit Qru; Plate 1) is poorly consolidated dark brown to red alluvium consisting of gravel, sand, silt and minor clay (Busacca et al., 1989, Helley and Harwood, 1985). West of the Feather River, the Riverbank Formation is present near the town of East Biggs (Plate 1). Soils developed on the Riverbank formation are the Gridley clay loam and the Redding gravelly sandy loam (Carpenter et al., 1926).

The latest Pleistocene Modesto Formation is informally divided into two members: a lower (older) unit that is (about 29,000 to 49,000 years old), and consists of unconsolidated slightly weathered gravel, sand, silt and clay; and an upper member, a younger unit, that is about 12,000 to 26,000 years old (Helley and Harwood, 1985). The upper Modesto (map unit Qmu) consists of sand, silt, and some gravel, and is associated with a moderate amount of secondary (pedogenic) clay accumulation. This clay-rich horizon may form laterally continuous zones of low hydraulic conductivity, and may extend across boundaries between coarse and fine-grained strata within the latest Pleistocene alluvium. Soils developed on the Modesto Formation include the Gridley loam of Strahorn et al. (1909) and the Conejo complex of Lytle et al. (1988), both of which are associated with a shallow “siltstone” horizon, or duripan (hardpan).

Latest Holocene deposits overlie or are inset into the Modesto Formation, and are categorized as channel, floodplain, and basin deposits (stratigraphic correlation chart; Plate 1). Channel deposits include Holocene channels (Hch), sloughs (Hsl), in-stream or lateral bars (Hb), and meander scrolls (Hms). These deposits likely consist of fine to coarse sand, silty sand, and clayey sand, with trace fine gravel. Holocene channel deposits (Hch) present along the western map area as secondary channels, contain fining-upward sequences of sand, silt and clay. These sloughs (map unit Hsl) are former channels associated with Live Oak and Morrison Sloughs (Plate 1), and are likely filled with a fining upward sequence of silt and clay.

Holocene floodplain deposits include crevasse splays (Hcs), and overbank deposits (Hob) and are typically deposited by non-channelized flow. Crevasse splays (Hcs) are from breaching of river banks or natural levees and are usually sand rich. Overbank deposits form by localized overtopping of river banks or natural levees, and subsequent deposition from shallow sheet flow or standing water.

Undifferentiated Holocene and Quaternary alluvium (Ha and Qa, respectively) usually occur proximal to or within the river channel, (Plate 1). The undifferentiated map unit is used in areas where geomorphic features are obscured or obliterated by historical (1937-era) agriculture. The deposits within these agriculturally modified areas are assigned a relative age (Ha or Qa) based on overlapping and cross cutting relationships with the surrounding deposits as follows: Ha if the agriculture-modified area is mapped within or shown overlying Holocene deposits; Qa where it is difficult to evaluate the age based on the relationship with nearby deposits. Soils associated with these undifferentiated units (Qa) are the Sacramento silt loam and Sacramento fine sandy loam, (Strahorn et al., 1909), and the Columbia fine sandy loam of Lyle et al. (1988), which are poorly-developed soils commonly associated with relatively young deposits (i.e. Shlemon, 1967).

Historical deposits mapped in the Northern Feather Study area include channel and floodplain deposits, as well as artificial fill deposits (Plate 1). Historical deposits are estimated to be less than about 150 years old, dating from approximately 1800 to 1937. Historical stream channels (Rch), and overflow channels (Rofc) transport high stage water flow across the ground surface outboard of the levees. These channel deposits likely consist of silt and sand with traces of gravel. The upper few feet of these deposits probably are filled with debris derived from upstream hydraulic mining activities. Lateral bar deposits (Rb) and meander scrolls (Rms) are located adjacent to the present-day Feather River, and are generally present inboard (waterside) of the present-day Feather River levees. In the northern part of the study area, directly south of Thermalito, are multiple anastomosing chutes (map unit Rcu; Plate 1). These chutes are similar to overflow channels in that they transport water flow during high river stage across the ground surface outboard of the levees. These chutes are entrenched into fluvially deposited hydraulic mining debris, and likely have filled with re-worked mining debris. Historical sloughs transport water collected from sheet flow and overland flow west of the Feather River southerly toward the Sutter Basin (i.e., Live Oak and Morrison Slough). Slough deposits (Rsl) likely consist of fining-upward silt and clay. Historical flood plain deposits include crevasse splay (Rcs), and overbank (Rob) deposits, which generally consist of a gradational or abrupt fining upward sequence of sand, silt, and clay. Historical overbank (Rob) deposits are slightly finer grained sand, silt, and clay deposited via sheet flow. These historical deposits are differentiated from older deposits based on cross-cutting and superposition relationships relative to cultural features visible on the 1937 photographs.

Historical alluvial deposits (Ra), generally located between the Feather River channel levees, and on the land side of the levees in the area directly south of the Thermalito Afterbay, consist of undifferentiated sand, silt, and minor lenses of gravel. Soils associated with this sandy alluvium are the Columbia very fine sandy loam and Columbia loam, as shown on the Soil Survey Map of the Oroville Area (Carpenter et al., 1926). This series of soils has been correlated with Holocene age deposits by Shlemon (1967). Historical artificial fills are culturally-emplaced heterogeneous deposits, with varying amounts of clay, silt, sand, and gravel from local sources. These deposits include levee structures and canal levee systems (map unit L; Plate 1) and dredge tailings (map unit DT).

The distribution of historical and Holocene deposits shown on Plate 1 generally is consistent with early, less-detailed soil survey mapping along the western banks of the Feather River as areas of Marcuse clay loam, Gridley loam, Sacramento Series fine sand, sandy loam and silt loam and the Columbia very fine sandy loam soils (Strahorn et al., 1909; Carpenter et al., 1926). The Gridley loam occurs along the northern Feather River from the Thermalito Afterbay south to the confluence with the Bear River, and closely corresponds to the Modesto Formation of Helley and Harwood (1985). The relationship between the mapped surficial geologic units and the potential for underseepage is summarized below.

5.0 Geomorphic Conceptual Model

This section provides a preliminary geomorphic conceptual model based on general relationships among surface and subsurface geologic deposits along the western side of the Feather River, as described above and shown on Plate 1. This conceptual model provides a consistent basis for understanding the type and distribution surficial geologic deposits, primary geomorphic processes, and shallow subsurface stratigraphy in the study reach. This conceptual model does not address planform or gradient changes of the Feather River itself, nor the susceptibility of stream banks to erosion. Future studies of these changes would be valuable in understanding process response of the Feather River, and provide key data for estimating rates of channel changes (i.e. lateral migration). However, these analyses are not directly relevant to evaluating the possibility of underseepage with respect to levee stability.

Published geologic maps of the project area show a complex series of westward aggrading alluvial fans and terraces derived from erosion of the Sierra Nevada, identified as the Riverbank and Modesto Formations (Bussaca et al., 1989; Helley and Harwood, 1985; Creely, 1965). The Riverbank Formation and Modesto Formation in general are semi-consolidated to unconsolidated deposits characterized by intraformational paleochannels and lateral and vertical stratigraphic complexity related to past fluvial processes and buried paleo-topography. The oldest map unit, the Riverbank Formation unconformably overlies the Pliocene-Pleistocene age Laguna Formation, which consists of interbedded alluvial gravel, sand and silt (Busacca et al., 1989; Helley and Harwood, 1985). The overlying Pleistocene Riverbank Formation consists of very dense gravel deposits that are, in turn, overlain by a medium dense sand and gravelly sand package of the latest Pleistocene Modesto Formation (Busacca et al., 1989). The upper member of the Modesto Formation is exposed at the ground surface adjacent to the western bank of the Feather River. The Modesto Formation is locally mantled by unconsolidated, sand rich Holocene deposits (Plate 1). East of the Feather River the older stratigraphic units are uplifted and dissected and younger deposits are inset into them with older deposits buried beneath younger deposits. West of the Feather River, the stratigraphic units are found in typical succession. This is the result of overall westward tilting and uplift of the Sierra Nevada, incision along the tributary drainages (i.e. Honcut creek), and progradational fan deposition west of the river.

Surficial geologic mapping (Plate 1) shows differences in deposit type and distribution from north to south along the northern Feather River study area, which are primarily associated with proximity to the Sierra Nevada mountain front near Thermalito Afterbay. These differences illustrate the diversity of past geomorphic processes along the river and, as a consequence, the type of geologic deposits at and near the ground surface. The surficial geologic map allows the delineation of reaches along the river within which geomorphic processes and their associated deposits appear to be relatively consistent.

The northern Feather River project area is divided into three reaches based on characteristic deposit types and distributions. The levee reaches are numbered Northern Feather one through three (NF-I through NF-III), sequentially from north to south (Figure 2, Plate 1). This section describes the surficial geologic characteristics of Reach NF-I, NF-II, and NF-III of the Feather River between Thermalito Afterbay and Yuba City.

5.1 Reach NF-I

Reach NF-I extends from the Thermalito Afterbay to Reimer Road and is about 11.1 levee miles long (Plate 1). Widespread deposits of historical alluvium (map unit Ra) blanket the area adjacent to the Feather River along the length of this reach where the river flows in the Sacramento Valley. Much of this unconsolidated historical alluvium contains clasts from many source lithologies and is derived from hydraulic mining debris (James, 1999). A complex pattern of anastomosing chutes or cut-off channels (map unit Rcu) eroded the historical alluvium by 1937 (Ra). These chutes underlie the project levees along the length of this reach (Plate 1). Project levees were built after 1937 along NF-I, from Thermalito Afterbay south to Ord Ranch Road.

Hardpan horizons were not identified in subsurface data along this reach, suggesting a substantial thickness of unconsolidated alluvial deposits unconformably overlying the Modesto Formation. Three alluvial units were identified in subsurface data overlying a semi-consolidated alluvial unit that we identified as the lower member of the Modesto Formation. Boreholes revealed an approximately 20-foot-thick package of young, unconsolidated silty sands and sandy clays, above a 10 to 16 foot thick silty sand, and 15-to 20-foot-thick gravel bed (Figure 3).

Hydraulic mining debris was dredged for its gold content along the northern half of the river banks along this reach, from Lapkin Road at Thermalito Afterbay to the area just south of Almond Avenue (Plate 1). Some dredge tailing spoils were apparent in 1937 aerial photography, though the majority of dredge tailing spoils post-date these air photos. The full extent of dredging tailing is apparent in modern USGS topographic maps (i.e. USGS, Biggs topographic quadrangle, 1:24,000 scale, 1970) and is shown on this surficial geologic map (map unit DT). Chutes (map unit Rcu) present in 1937 aerial images, though now obliterated by dredge operations are shown as dotted contacts in the Surficial Geologic Map (Plate 1). In this area project levees either overlie or bound the western edge of the Dredge Tailings (map unit DT). South of the dredged areas, the levee along Ord Ranch Road overlies deposits that fill an abandoned channel meander, map unit Hch (Plate 1). This abandoned meander matches the present river geometry and possibly reflects a southward migration of this meander within the active channel.

5.2 Reach NF-II

The second reach of the north Feather River project area, NF-II, extends from Reimer Road to Sanders Road, and has a length of about 9.4 levee miles. In this reach the project levee is typically perched at the top of a 5- to 15-foot-high east-facing escarpment cut into the Modesto Formation. The active meander belt of the Feather River with its flood plain, meander scrolls, and channel deposits, lies to the east of the levee at the base of the escarpment. West of the escarpment, historical overbank (Rob) and crevasse splay (Rcd) deposits locally overlie the Modesto. They represent locations where flooding of the Feather River overtopped the escarpment in the past and are assumed to pre-date the construction of the levee. An extensive continuous Holocene natural levee deposit has not built up along reach II, in contrast to reach I. The river may be incised too deeply below the surface of the Modesto Formation for floods to regularly overtop the escarpment.

Most of the Reach II levee sits directly on Modesto Formation with about 3.5 of the 9.4 miles of the levee sitting on the above-mentioned Holocene overbank and crevasse splay deposits that overlie Modesto Formation. Borehole WL0009_004S (Plate 1), located in the southern portion of this reach, shows project levee fill directly above the hard, consolidated Modesto Formation.

5.3 Reach NF-III

Levee reach NF-III extends from Sanders Road at the north to Yuba City at the south, and is about 4 miles in length (Plate 1). Along this reach the project levee almost entirely overlies Historical alluvial deposits that mantle, or crosscut the Modesto Formation. Crevasse splay (Rcs), overflow channels (Rofc), historical alluvium (Ra), channel deposits (Rch), and overbank deposits (Rob) are present along this reach. Crevasse splay deposits are present at the northern end of NF-III (Sanders Road, Plate 1), directly adjacent to a westerly bend of the Feather River. Aerial photography from 1937 shows multiple generations of crevasse splay deposits at this location. The levee appears to be constructed overtop these deposits. A pump station is noted on the 1970’s topographic map, suggesting this location may have had seepage problems.

Immediately south of Sanders Road, an overflow channel (map unit Rofc) diverges from the Feather River, transporting flow outboard of the levees, and flowing back into the river about 1.5 miles south at Rednall Road (Plate 1). The overflow channel likely consists of a fining upward sequence of sand, silt, clay and some gravel, and could be slightly incised into the Modesto Formation. Undifferentiated historical alluvium (map unit Ra) underlies the levees within the area directly east of these overflow channels. This alluvium was laid down over the surface of the Modesto Formation by unchannelized flow of the Feather River (Plate 1). Historical channel deposits (map unit Rch) from the Feather River underlie about 0.7 miles of the levees north of Rednall Road (Plate 1). Overbank deposits are present near Pease Road (Plate 1) and continue along the levee for about 0.5 miles. Historical crevasse splay and overbank deposits likely consist of a massive to fining upward sequence of sand and silt derived from upstream hydraulic mining activities.

6.0 Applications to the Urban Levee Project

Based on an initial analysis of surface and subsurface geologic and geomorphic data, the levee bordering the western side of the Feather River from the Thermalito Afterbay to Yuba City, overlies three different types of deposits, Reach NF-I overlies a thick package of historical alluvium, NF-II directly overlies the Modesto Formation with local areas of historical alluvium, and Reach NF-III directly overlies a continuous blanket of sediment derived from historical crevasse splay (Rcs), overflow channel (Rofc), alluvium (Ra), channel (Rch) and overbank (Rob) deposits, above the Modesto Formation. The preliminary conceptual surface and subsurface geologic relationships as they relate to levee structures and potential underseepage along each reach of the river are described below. This study does not account for any existing seepage mitigation structures (i.e. cutoff walls) that may be present.

Along Reach NF-I the levees are underlain by a package of young coarse-grained fluvial sediment, most likely of mining debris origin, and chutes filled with coarse grained fining upward sequences of sediment also derived from hydraulic mining debris (Figure 3). This material is laterally extensive and poorly consolidated, with localized chute deposits (map unit Rcu). The chutes extend beneath the levee with an orientation that is roughly orthogonal to the levee crest, and may provide relatively high conductivity pathways for levee underseepage within the already very permeable fluvial sediments. The sediments along the northern half of reach NF-I were dredged for gold during the first half of the 20th century, well-graded dredge tailings remain in these areas. Dredge tailings are unconsolidated and consist of silt, sand, and gravel. At the north near Vance Avenue the project levees appear to overlie these highly permeable tailings, and everywhere else bound the western edge of the tailing spoils. Levees along this entire reach are judged to be highly susceptible to underseepage.

Levee reach NF-II is likely underlain by a combination of coarse grained, semi-consolidated alluvium of the Modesto Formation and localized areas of historical, poorly consolidated coarse-grained avulsion deposits (overbank and crevasse splay deposits) overlying the Modesto Formation. These avulsion deposits likely are permeable and may provide localized areas susceptible to underseepage. Project levees underlain by the Modesto Formation likely are less susceptible to underseepage problems, however the natural variability within the Modesto may also provide local pathways for underseepage.

Levee reach NF-III generally consists of westward aggrading avulsion deposits overlying the Modesto Formation. The levee is underlain by coarse-grained, poorly consolidated silt, sand and gravel, blanketing the consolidated Modesto Formation and in some places incised into the Modesto Formation. These deposits likely are permeable and susceptible to underseepage.

In summary, lateral and vertical variabilities in the shallow subsurface deposits have resulted from past fluvial geomorphic processes. Surficial geologic mapping along the north Feather River allows reach classifications within which conditions may be relatively similar. The conceptual geomorphic framework suggests that stratigraphic relationships may promote localized levee underseepage, given certain hydraulic conditions throughout the Northern Feather River Study area, particularly along reach NF-I. Areas where levees may overlie historical or Holocene-age coarse grained deposits are of special concern. Further spatial analyses of the surficial geologic mapping and subsurface geotechnical exploration data are needed to better constrain and characterize areas that are most susceptible to underseepage in the study area. We anticipate that this conceptual model will be revised and updated as new information becomes available.

7.0 Limitations

This geomorphic assessment and associated data interpretation have been performed in accordance with the standard of care commonly used as the state-of-practice in the geologic engineering profession. Standard of care is defined as the ordinary diligence exercised by fellow practitioners in this geographic area performing the same services under similar circumstances during the same time period.

Discussions of surface and subsurface conditions summarized in this technical memorandum are based on geologic interpretations of subsurface soil data at limited exploration locations available to this assessment through September of 2007. Variations in subsurface conditions may exist between exploration locations, and the project team may not be able to identify all adverse conditions in the levee and its foundation. This memorandum is for the use and benefit of DWR. Use by any other party is at their own discretion and risk.

8.0 References

Busacca, A.J, Singer, M.J., and Verosub, K.L., 1989, Late Cenozoic Stratigraphy of the Feather and Yuba Rivers Area, California, with a Section on Soil Development in Mixed Alluvium at Honcut Creek, USGS Bulletin 1590-G.

Carpenter, E.J., Strahorn, A.T., and Glassey, T.W., 1926, Soil Survey of the Oroville Area, California; 1:62,500, USDA Bureau of Soils.

Creely, R.S., 1965, Geology of the Oroville Quadrangle, California, California Division of Mines and Geology Bulletin 184, 86p.

Department of Water Resources (DWR), 2004, SP-G2: Effects of Project Operations on Geomorphic Processes Downstream of Oroville Dam, Task 6 – Channel Meanders and Bank Erosion Monitoring, Oroville Facilities Relicensing FERC Project No. 2100, July.

Ellis, W.T., 1939, Memories: My Seventy-two Years in the Romantic County of Yuba, California (Memoirs of Marysville Levee Commissioner), p.103.

Helley, E.J., and Harwood, D.S., 1985, Geologic map of the late Cenozoic deposits of the Sacramento Valley and Northern Sierran foothills, California; 1:62,500, USGS Map File MF-1790.

James, A., 1999, Time and the Persistence of Alluvium: River Engineering, Fluvial Geomorphology, and Mining Sediment in California; Geomorphology, v. 31, p. 265 – 290.

Llopis, J.L., Smith, E.W., and North, R.E., 2007, Geophysical Surveys for Assessing Levee Foundation Conditions, Sacramento River Levees, Sacramento, CA; US Army Corps of Engineers, Engineer Research and Development Center, Geotechnical and Structures Laboratory publication ERDC/GSL TR-07-21, 61p.

Lytle, D.J., Kurowski, R.G., Whiting, M.L., Vinson, E.N., Vonich, P.W., Hansen, R.W., 1988, Soil Survey of Sutter County, California, 1:24,000, USDA Soil Conservation Service.

Page, R.W., 1986, Geology of the Fresh Ground-Water Basin of the Central Valley, California, with Texture Maps and Sections; US Geologic Survey Professional Paper 1401-C, 54 p., 5 plates.

Shlemon, R.J, 1967, Landform-Soil Relationships in Northern Sacramento County, California, Ph.D. dissertation, University of California Berkeley, CA.

Strahorn, A.T., Mackie, W.W., Holmes, L.C., Westover, H.L., Van Duyne, C., 1909, Soil Survey of the Marysville Area, California; 1:62,500, USDA Bureau of Soils.

USGS, Biggs topographic quadrangle, surveyed 1909-1910, published 1912; map scale 1:31,680, five foot contour interval.

USGS, Gridley topographic quadrangle, surveyed 1909-1910, published 1912; map scale 1:31,680, five foot contour interval.

USGS, Honcut topographic quadrangle, surveyed 1909-1910, published 1912; map scale 1:31,680, five foot contour interval.

USGS, Oroville topographic quadrangle, surveyed 1910, published 1912; map scale 1:31,680, five foot contour interval.

USGS, Palermo topographic quadrangle, surveyed 1910, published 1912; map scale 1:31,680, five foot contour interval.

USGS, Sutter topographic quadrangle, surveyed 1909, published 1911; map scale 1:31,680, five foot contour interval.

USGS, Yuba City topographic quadrangle, surveyed 1909, published 1911; map scale 1:31,680, five foot contour interval.

USGS, Biggs topographic quadrangle, published 1952, remapped 1970; map scale 1:24,000, five foot contour interval.

USGS, Gridley topographic quadrangle, published 1952, remapped 1973; map scale 1:24,000, five foot contour interval.

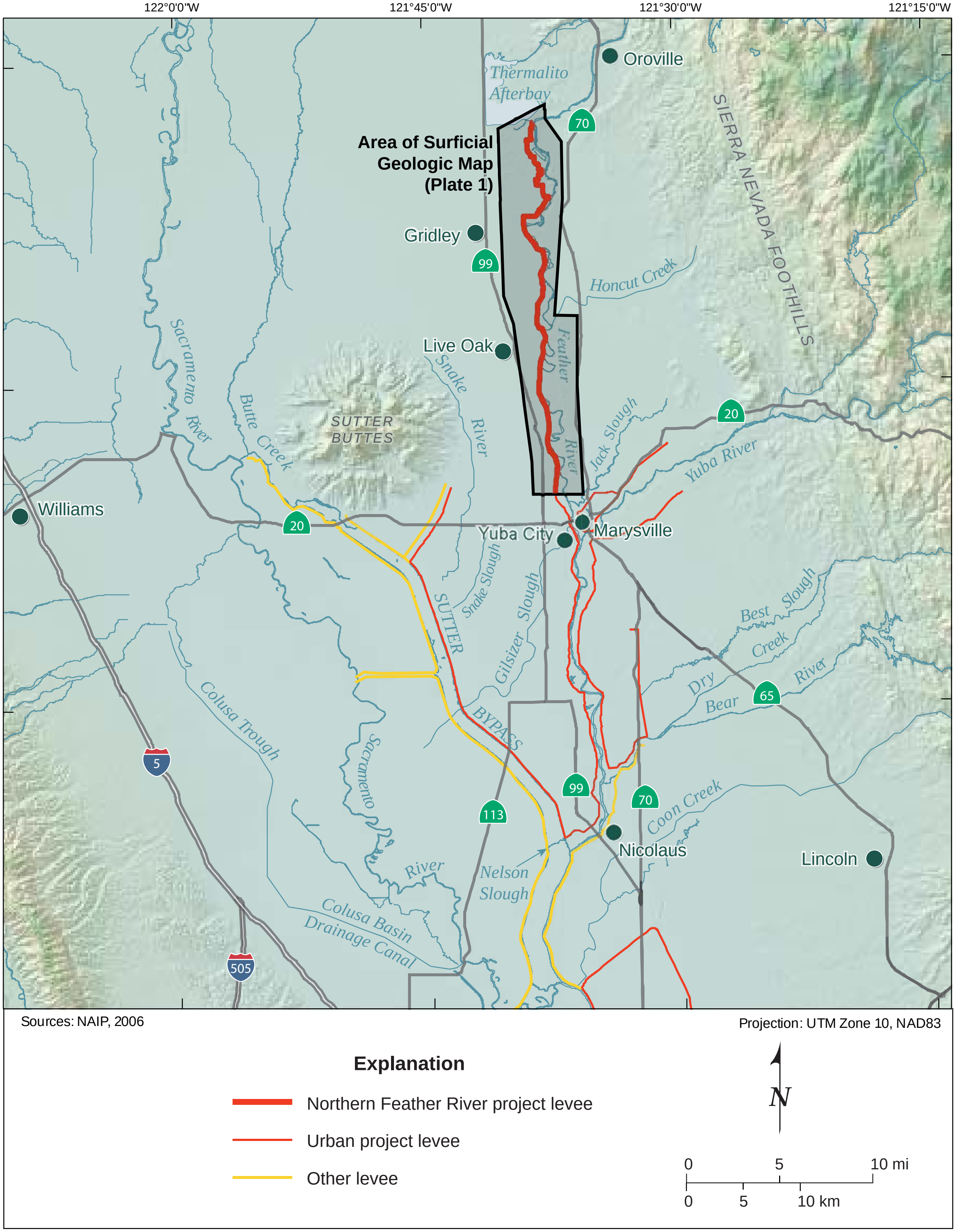
USGS, Honcut topographic quadrangle, published 1952, photo revised 1973; map scale 1:24,000, five foot contour interval.

USGS, Oroville topographic quadrangle published 1952, photo revised 1973; map scale 1:24,000, five foot contour interval.

USGS, Palermo topographic quadrangle published 1952, remapped 1970; map scale 1:24,000, five foot contour interval.

USGS, Sutter topographic quadrangle, published 1952, photo revised 1973; map scale 1:24,000, five foot contour interval.

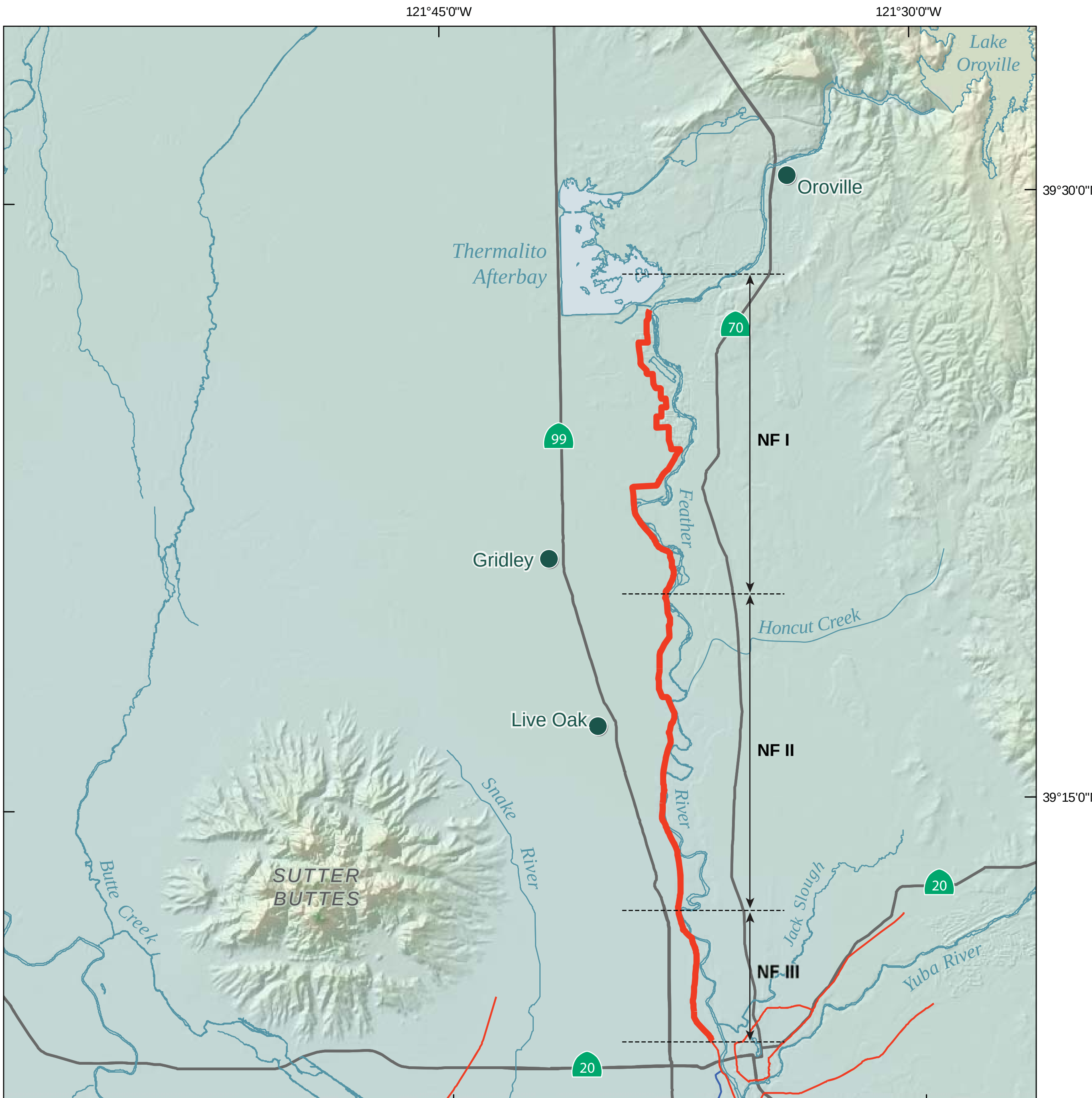
USGS, Yuba City topographic quadrangle, published 1952, photo revised 1973; map scale 1:24,000, five foot contour interval.



WLA **Map of Central Valley near Sutter Buttes, California**

DWR URBAN LEVEE PROJECT

Figure 1



Sources: NAIP, 2006

Projection: UTM Zone 10, NAD83

Explanation

Northern Feather River project levee

Urban project levee

NF I — Reach of Northern Feather River Study Area

N

0 — 5 mi

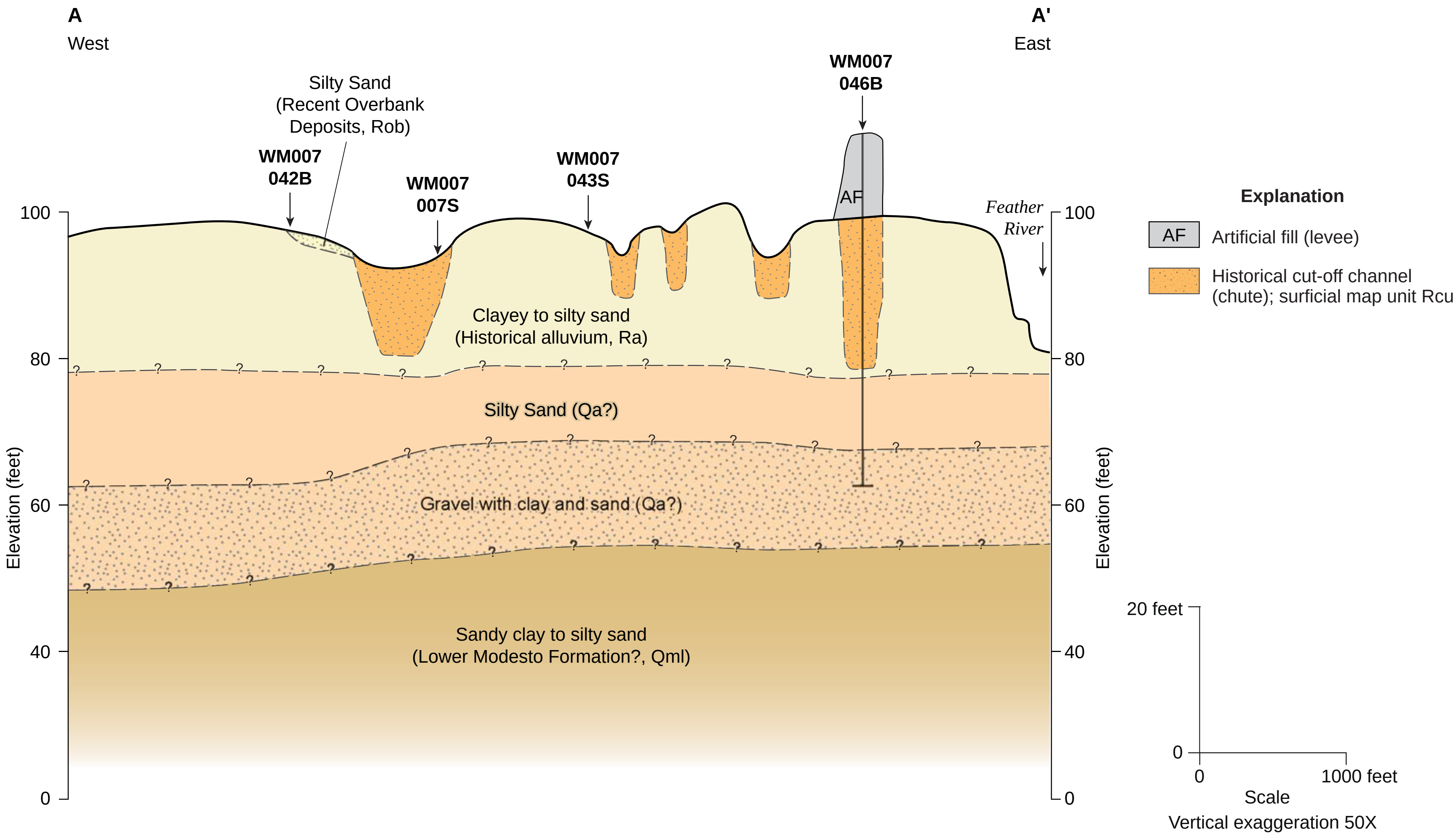
0 — 5 km

WLA

Map of the Reaches Identified along the Northern Feather River Study Area

DWR URBAN LEVEE PROJECT

Figure 2



WLA

Conceptual Subsurface Diagram across the Northern Feather River, A-A'

DWR URBAN LEVEE PROJECT
Figure 3

Plate 1 - Surficial Geologic Map of the Feather River, Northern Section
This map shows surficial geologic deposits and levees as they existed in 1937. Map units and boundaries are drawn by interpretation of historical aerial photography supplemented by data from historical maps and surveys. For reference, the mapping is superimposed on modern U.S. Geological Survey topographic base map prepared in 1952 and photo revised in 1973. See accompanying report for complete descriptions of map units, process descriptions and methodology.
Explanation
Geologic contact; dashed where approximate, dotted where concealed, queried where uncertain; solid contacts within 30' of line shown on map.
Geologic unit destroyed by Dredge mining operations, contacts present in 1937 air photos and historical 1909-1910 series topographic maps.
NF-II
Geomorphic Reaches discussed in text for Northern Feather River study Area.
Project Levees
Canals as mapped from 1937 photos.
A A'
Cross Section
WM0007_004S
Borehole locations from URS, Corp; locations from Sutter P2 Boring Locations, Region 1 Northern Area map.
W 1911
Water bodies shown on 1911 historic topographic maps.
W 1937
Water bodies, circa 1937.
BP
Borrow pits present in 1937.
Geologic Units
HISTORICAL
L
Levees (artificial fill), circa 1937.
DT
Dredge tailings; spoils material from gold dredge operations. Map unit boundary from USGS Biggs 7.5-minute quadrangle, 1970.
Rob
Overbank deposits; sand, silt, and clay; deposited during high-stage water flow, overtopping channel banks.
Rcs
Crevasse splay deposits; fine to coarse sand, with minor lenses of clay deposited from breaching of natural or artifical levees.
Rch
Channel deposits; well sorted sands and fine gravels (Rch 1911: channels as shown on historic topo).
Rb
Channel bar deposits; fine gravel, sand, and silt deposited in or along channel lateral margins.
Rcu
Cut off channel (chute); occurs on insides of meander bends within the river channel; on flood plain – entrenchment of overflow channels into hydraulic mining debris.
Rofc
Overflow channels; vertically stratified sand, silt, and clay in floodplain channels occupied primarily when high-stage water overtops channel banks.
Rsl
Slough deposits; sand, silt and clay, fining upward facies, low-energy channel deposit.
Ra
Alluvial deposits, undifferentiated; sand, silt, and minor lenses of fine gravel.
HOLOCENE
Hob
Overbank deposits; sand, silt, and clay; deposited during high-stage water flow, overtopping channel banks.
Ha
Alluvial deposits; undifferentiated; sand, silt, and minor lenses of gravel; under cultivation in 1937.
Hch
Channel deposits; sorted sands and silts; fining upward.
Hms
Channel meander scroll deposits; sand, silt and clay from lateral channel migration.
Hsl
Slough deposits; sand, silt and clay, fining upward facies, low-energy channel deposit.
Qa
Alluvial deposits, undifferentiated; sand, silt, and minor lenses of gravel; under cultivation in 1937.
PLEISTOCENE
Qmu
Modesto Formation; upper member; unconsolidated gravel, sand, silt, and clay.
Qml
Modesto Formation; lower member; unconsolidated to semi-consolidated gravel, sand, silt and clay.
Qru
Riverbank Formation; upper member, semi-consolidated to consolidated gravel, sand, silt and minor clay.
Qrl
Riverbank Formation; lower member; consolidated gravel, sand, silt, and clay, generally associated with strong duripan horizon.
Stratigraphic Correlation Chart
Time
Depositional Environment
Epoch
Channel deposits
Floodplain and alluvial-fan deposits
Cultural deposits
Historical
Rch
Rb
Rcu
Rsl
Rofc
Ra
Rcs
Rob
Qa
L
DT
Holocene
Hch
Hms
Hsl
Ha
Hob
Latest Pleistocene
Pleistocene
Qmu
Qml
Qru
Qrl
THERMALITO BAY
LAPKIN ROAD
ALMOND AVE
ORD RANCH RD
MORRISON SLOUGH
REIMER RD
LIVE OAK SLOUGH
LIVE OAK
SANDERS RD
REYNALDS RD
NF-I
NF-II
NF-III
HONCUT
MARYSVILLE
Palermo
1:20,000
N
0 0.5 1 Miles
0 0.5 1 Kilometers
Map projection: NAD83 UTM Zone 10N
Topo base USGS quadrangles:
USGS, Biggs topographic quadrangle, published 1952, remapped 1970; map scale 1:24,000, five foot contour interval.
USGS, Gridley topographic quadrangle, published 1952, remapped 1973; map scale 1:24,000, five foot contour interval.
USGS, Honcut topographic quadrangle, published 1952, remapped 1973; map scale 1:24,000, five foot contour interval.
USGS, Palermo topographic quadrangle, published 1952, remapped 1970; map scale 1:24,000, five foot contour interval.
USGS, Sutter topographic quadrangle published 1952, photo revised 1973; map scale 1:24,000, five foot contour interval.
USGS, Yuba City topographic quadrangle, published 1952, photo revised 1973; map scale 1:24,000, five foot contour interval.
WLA WORK ORDERS 3 & 7 - SUTTER COUNTY
DWR URBAN LEVEE PROJECT
Plate 1 - Surficial Geologic Map
of the Feather River, Northern Section
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Walnut Creek, CA
1881_URS_Feather_North.mxd
09/04/2009
Geologic Mapping by J. Pearce and A. Streig
Digital Cartography by M. Ticci